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OF

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(INSTITUTED 1852.)

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PART D.

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International Engineering Congress,
held under the auspices of the Society,
St. Louis, Mo., October 3d to 8th, 1904.

Edited by the Secretary, under the direction of the Committee on Publications.

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1905.

INTERNATIONAL ENGINEERING CONGRESS, 1904.

Organization and Scope.—The Congress was undertaken, financed and conducted by the American Society of Civil Engineers, at the request of the Louisiana Purchase Exposition. Thirty-seven subjects were selected for consideration, and invitations to contribute papers were issued to specially selected engineers in America and abroad; each of these papers to be a review of progress during the past decade.

Papers and Discussions.—In response to this invitation ninety-seven such papers were received, nearly all of which were printed in advance form and distributed prior to the Congress for the purpose of eliciting discussion. The nationality of the authors of these papers is as follows:

United States, 51,	Holland, 7,	Belgium, 1,	Russia, 1,
France, 18,	Japan, 5,	Canada, 1,	Switzerland, 1.
England, 10,	Austria, 1,	Denmark, 1,	

One hundred and twenty-four additional written communications have also been received, which, together with the oral discussions at the Congress, after revision by the speakers, form part of this Congress publication.

Meetings.—The Congress was divided into eight Sections: Waterways, Municipal, Railroads, Materials of Construction, Mechanical, Electrical, Military and Naval, and Miscellaneous, and twenty-eight sectional meetings were held. There were also two general meetings of the Congress. The total registered attendance was 876, and the average attendance at each sectional meeting about 50.

Publications.—This Volume is one of six containing the Papers and Discussions of the Congress, published by the Society as Parts A, B, C, D, E, and F, of Vol. LIV of *Transactions*. In these volumes although it has not been possible to retain the subdivision by Sections, and no special grouping of subjects has been attempted, the papers and discussion on each subject are grouped. With each volume there is a table of Contents, and the last volume contains an Index covering the entire publication.

CHAS. WARREN HUNT,
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NEW YORK, FEBRUARY 25TH, 1905.

INTERNATIONAL ENGINEERING CONGRESS.

ST. LOUIS, MO., OCTOBER 3d TO 8th, 1904.

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ST. LOUIS, MO., OCTOBER 3d TO 8th, 1904.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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1904.

NAVAL ARCHITECTURE.

Congress Paper No. 45.

NAVAL ARCHITECTURE IN GREAT BRITAIN.

By Sir William H. White, K. C. B., F. R. S., President, Inst. C. E., Late Director of Naval Construction, London, England.

Congress Paper No. 46.

THE DEVELOPMENT OF JAPANESE SHIPBUILDING.

By S. Terano, Dr. Eng., Professor of Naval Architecture, Imperial University, Tokio, Japan.

Congress Paper No. 47.

EXPERIMENTS ON VIBRATION OF THE JAPANESE TORPEDO-BOAT DESTROYERS, *HARUSAME* AND *HAYATORI*.

By F. P. Purvis, F. Omori, S. Terano and C. Shiba, Professors, Imperial University, Tokio, Japan.

Discussion on the Subject by

L. E. Bertin, Paris, France.
William P. Craighill, Charlestown, W. Va., U. S. A.
E. L. Corthell, New York City, U. S. A.
W. F. Durand, Stanford University, Cal., U. S. A.
Sir William H. White, London, England.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

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INTERNATIONAL ENGINEERING CONGRESS,
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NAVAL ARCHITECTURE.

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By Sir William H. White,* K. C. B., F. R. S.,
President, Inst. C. E.

At the request of the Committee this paper has been prepared, in order to place before the International Engineering Congress a summarized statement of the development of naval architecture in Great Britain during the last ten years. Within the limits of space assigned, it is only possible to indicate the principal advances made in methods of ship construction and propulsion; some points of interest and practical importance have necessarily been omitted.

British Warship Building in 1894.

It will be convenient to note at the outset the conditions prevailing in British Shipbuilding in 1894. In many respects that date is notable. In regard to warships, it marked the practical completion of the great programme of construction which had been embodied in the Naval Defence Act, 1889. Under that Act provision had been made for adding 70 ships of various classes to the navy,

* Late Director of Naval Construction, England.

including 10 battleships, 9 first-class cruisers, 29 second-class cruisers, 4 third-class cruisers and 18 torpedo gunboats. The original estimated cost of these vessels and their armaments was 21½ millions sterling. In certain classes, modifications were made and dimensions increased as the programme was executed, in order to obtain greater fighting and sea-keeping capabilities. About a million sterling was thus added to the cost; the fact being recognized when the changes were authorized. The actual outlay on the 70 ships was about 22¾ millions sterling; about four-fifths of that sum being expended on hulls, armour, machinery and gun-mountings, and one-fifth on guns, torpedoes and ammunition. Taking into account the fact that the vessels were of novel types, of unprecedented speed, and armed with the first quick-firing guns of large caliber, this was a remarkably close approximation between estimate and expenditure. Thanks to the splendid resources of the United Kingdom in shipyards, engine-factories and steel works, the programme was practically completed within the five years contemplated, although that period was marked by abnormal activity in mercantile shipbuilding, about 5½ millions of tons of new ships having been launched in the years 1889-93.

Having been responsible for the designs of these seventy ships, as well as for the estimates of total cost and distribution of expenditure over the quinquennial period, and having also been charged with the direction of the work of construction and the supervision of the manufacture of armour and other materials, it is naturally a matter of satisfaction to record the successful accomplishment of this undertaking, which was pronounced to be impracticable by many authorities. But it is pleasant to add that this result was chiefly due to the magnificent shipbuilding, engineering and metallurgical establishments of Great Britain, established and maintained by private enterprise. Even for the thirty-eight ships built in Government dockyards, private firms provided all the materials, the machinery, the armour, and a large proportion of the armament, the contribution of the dockyards being confined to the labour—representing an aggregate cost of about £3 750 000—expended in the combination of materials and mechanisms furnished by private industry.

This was the first great programme of construction for the Royal Navy carried out on definite and systematic lines. It stands alone

in having been published in its entirety before the work began. Since 1894 there have been other programmes, some of them of greater magnitude. These programmes have been dealt with, officially, as elaborately as the Naval Defence Programme, and have been carried through with equal success. In these cases, however, there has not been previous publication of the full programme, but only of such parts as were included in current naval estimates. Of the two systems, it would appear that the latter is undoubtedly to be preferred. It is obvious that when a programme is disclosed beforehand in its entirety, as was done with the Naval Defence Act, competitors are fully informed and can make arrangements (working on a plan mutually devised or under a common agreement) by which the effort decided upon by Great Britain can be matched and neutralized. On the other hand, as Great Britain possesses an enormous superiority in shipbuilding resources, and can produce vessels more rapidly and at less cost, it is her wisest policy to publish only the programme of construction for each year, based on the numbers and types of vessels which may have been laid down abroad, taking care that the completion of British ships shall always be secured before that of corresponding foreign types.

Battleships of 1894.—In 1894 the largest battleships in the Royal Navy were vessels of the *Royal Sovereign* class, 380 ft. in length, 75 ft. in breadth, of 14 150 tons displacement and 17½ to 18 knots maximum speed, carrying four 13½-in. guns and ten 6-in. quick-firing guns, besides smaller weapons. The largest cruisers afloat were the *Blake* and *Blenheim,* designed in 1888. They are 375 ft. in length, 65 ft. in breadth, about 9 100 tons displacement, with a maximum speed of 22 knots.

Cruisers of 1894.—The first-class cruisers of the *Edgar* class, built under the Naval Defence Act, were somewhat smaller than the *Blake* and *Blenheim*, and their maximum speed was about 21 knots. The second-class cruisers were of two types: one of 4 300 tons, the other of about 3 500 tons. All had a speed of about 20 knots. All the cruisers had protective decks and no side armour. Battleships and cruisers had cylindrical tank boilers, with closed stoke-holds and forced draught.

Torpedo Gunboats of 1894.—The torpedo gunboats of the *Sharpshooter* class were designed as the smallest type capable of independent sea service and as adjuncts to a fleet. They were

230 ft. long, 27 ft. broad, of 735 tons displacement and were fitted with locomotive boilers intended to develop 4 500 h. p., corresponding to a maximum speed of 20 knots. Locomotive boilers, when fitted in "groups," failed to realize the intended power, although it should have been easily obtained on the basis of results secured with one or two boilers in many torpedo boats previously built. The sister ship, *Speedy,* was constructed (1892-93) with water-tube boilers of the Thornycroft type, and the stipulated engine power was easily realized; the original estimate for speed being verified on trial. This was the first vessel in the Royal Navy, above the size of torpedo boats, fitted with water-tube boilers. In recent years these vessels have been re-engined and fitted with water-tube boilers, attaining speeds of 21½ knots.

Armour.—The armour used on the ships of the Naval Defence Act was for the most part "steel-faced" iron; but in some of the vessels "all-steel" armour was introduced for the first time in the Royal Navy as the result of experiments which had been initiated in 1888. Nickel-steel armour of moderate thickness was used for the protection of superstructures.

Majestic Class.—In 1894 a further scheme of construction was begun, known as the "Spencer programme." This led to the design of battleships of the *Majestic* class. The characteristic features of these vessels are too well known to need detailed description. They are 10 ft. longer than the *Royal Sovereign* class and of 14 900 tons displacement. The disposition of the armour on the hull differed essentially from that of the *Royal Sovereign* class, the armour on the citadel being of uniform thickness and no water-line belt being fitted. The arrangements of the protective decks were modified. The use of "Harveyed" armour gave a large increase in defence for a given weight and thickness of armour, as compared with the "all-steel" armour, or the "steel-faced iron" armour, which had been previously used. The first experiments with Harveyed armour were made in England at the end of 1892, the system having been introduced to the Admiralty by a representative of the Harvey Company of the United States. English armour-plate makers had previously patented processes of a similar character; but action taken in the United States by Mr. Harvey and those who supported him, led to the perfection and practical adoption of this system. For

the principal armament of the *Majestic* class, guns of 12-in. caliber were adopted instead of the 13½-in. guns of the *Royal Sovereign* class. Had a satisfactory and well-proved type of 12-in. gun been available in 1889, it would have been adopted. The 13½-in. gun was used in the *Royal Sovereign* class because it was immediately available, and because past experience had shown that, in order to secure rapid and economical construction, it was absolutely necessary to determine the nature of the armament before the work of building warships was begun. This principle still holds good; neglect of it inevitably leads to delays, increased expenditure and other unsatisfactory results. The secondary armament of 6-in. quick-firing guns in the *Majestic* class was much better protected than that of the *Royal Sovereign;* the "casemate" protection being much extended, while greater facilities were provided for the service of ammunition along well-protected passages, lying low in the ship. Both these features had been recognized previously to be important, but equal effect had not been given to them in earlier designs. It is now universally admitted that the principles illustrated in the *Majestic* class are of paramount importance to fighting efficiency. With quick-firing guns and high explosives it is essential to provide adequate protection for the secondary armament, and for the men employed thereat, as well as for the transport of the ammunition. Large supplies are required with quick-firing guns, the magazines must be kept cool to prevent deterioration of the charges, and provision must be made for rapid supply of ammunition to the guns, if the full efficiency is to be realized. Provided these conditions are fulfilled, it may well prove advantageous to adopt less numerous but better protected armaments; and mere multiplication of guns may involve reduced fighting power. For defence against torpédo attacks a considerable number of quick-firing guns were mounted in all Naval Defence ships, and torpedo nets were fitted to the battleships and largest cruisers. By common consent the *Majestic* class is regarded as having greatly influenced all subsequent battleship construction.

Powerful and Terrible.—The year 1894 also witnessed the design of the protected cruisers, *Powerful* and *Terrible,* which were built for the purpose of meeting the Russian cruisers, *Russia* and *Rurik.* The water-line region of the Russian ships was protected, for a por-

tion of the length, by a narrow belt of vertical armour, and they carried a large number of guns practically destitute of armour protection. After full consideration of their offensive and defensive qualities, it was decided, in the *Powerful* and *Terrible,* to adopt a strong protective deck as the main defense of the vitals, rather than to fit a narrow belt of vertical armour over a portion of the length of the water line. It was also decided to accept a smaller number of guns, but to provide efficient armour protection for the 6-in. and 9.2-in. guns. The service of the ammunition was arranged, not merely so as to secure adequate and rapid supply, but to give thorough protection during its transport from the magazine to the guns. A great superiority in speed and coal supply was also secured in the *Powerful* and *Terrible,* their dimensions being correspondingly increased.

Perhaps the most notable feature in the vessels was the adoption of water-tube boilers of the Belleville type. This step has been strongly condemned on the ground that it was unwise in warships of such unprecedented power and speed to adopt a type of steam generator which was regarded as experimental. It is not necessary to justify what was done in these vessels; but it may be stated that the strong and capable committee, appointed four years ago by the Admiralty, to investigate the general subject of water-tube boilers fitted in warships, has approved the action which was taken by the Admiralty in 1894. Moreover, it is undoubted that, unless water-tube boilers had been adopted, the design of the *Powerful* and *Terrible* would have been impossible apart from greatly increased dimensions and cost. Even when favoured by the adoption of this light type of boiler, their dimensions far exceeded those of any other cruisers, although they were still much inferior in size to the largest and swiftest passenger steamers of that period. The length of the *Powerful* was 500 ft.; beam, 71 ft.; displacement, 14 200 tons; speed, from 22 to 22½ knots and horse-power, 22 000. As the vessels were intended for distant and long-continued sea service, it was decided to sheathe their bottoms with wood and copper, in order to prevent fouling and consequent loss of speed. These features involved more than 600 tons additional weight and increased the cost by about £45 000. If the vessels had been built with bare steel bottoms, like more recent cruisers, the displacement would

have been about 13 500 tons. This fact has been very generally overlooked by critics of the design, who ignore the importance attached by the Admiralty to sea-keeping capability and power of maintaining speed for long periods on stations where docks are not available. The adoption of water-tube boilers in the *Powerful* and *Terrible* was naturally followed in other classes of ships. In this policy, French naval authorities had led the way, and French experience was necessarily drawn upon when the new departure was under consideration. For a time battleships were still fitted with cylindrical tank boilers; but since 1896 there has been universal use of water-tube boilers for all classes of ships in the Royal Navy. Difficulties there have been, no doubt, as must have been anticipated with such a great experiment in a new direction. As experience has been gained, and the relative merits of competing types of boilers have been practically determined, these difficulties have been overcome. The great advantages obtainable with water-tube boilers have been confirmed, and their comparatively inferior economy in coal consumption has been remedied. The Admiralty Boiler Committee, in preliminary reports (1903) advised the use of a combination of tank and water-tube boilers in order to secure greater economy of coal when cruising at low speeds. In the writer's address in November, 1903, at the Institution of Civil Engineers,* he stated that this system was carefully considered in designing the *Powerful* class, and was set aside in favour of a complete installation of water-tube boilers. Further, he ventured the opinion that the Boiler Committee would eventually reach the same conclusion. It is interesting to note that this anticipation has already been realized, and that for the latest designs, the Committee has recommended the exclusive adoption of water-tube boilers for H. M. Ships. As yet the determination of the best types for use is still incomplete. Experience alone can settle that question, and it is probable that no single type will be found suitable for all conditions and classes of ships. The tank boiler has been brought to its present state of efficiency by a long period of use and successive steps in improvement. Critics of water-tube boilers fail to make allowance for their recent introduction, and the limited experience hitherto gained in actual sea service. But the advances, already made, are a guarantee of ulti-

* *Minutes of Proceedings*, Inst. C. E., Vol. CLV, 1903-04.

mate success and widely-extended use for water-tube boilers, if the steam engine continues to be used for ship propulsion.

Torpedo-Boat Destroyers.

In 1894 the earliest examples of torpedo-boat destroyers had just been completed and subjected to experiment. The results were so satisfactory that the Admiralty decided immediately to raise the total number of destroyers to 42, and in order to ensure rapid advancement of construction, the orders were widely distributed, and a flotilla was thus made ready for service in an unprecedentedly short time. The design of these vessels was based upon that of torpedo boats, but they were much larger; the length was about 200 ft. and displacement about 250 tons, with speeds of 27 knots. In consequence of their larger dimensions and armament of quick-firing guns, these destroyers could run down in a sea-way and destroy any torpedo boats of that period. They also carried a considerable torpedo armament, which at first was treated as alternative to the gun armament, but eventually carried in association therewith. Very considerable developments of the type have been made since 1894, and the lead of the Admiralty has been followed in all navies. Probably the most interesting circumstance in connection with the construction of these destroyers was the fact that when the necessity arose for rapid additions to this class, it was found possible to distribute the orders amongst fourteen firms, who undertook and successfully carried out the contracts; although up to that date Messrs. Thornycroft and Messrs. Yarrow had built nearly all the vessels of the torpedo flotilla constructed in England, while Messrs. White, of Cowes, and Messrs. Laird of Birkenhead, had undertaken some work of that class. There has been no more remarkable evidence of the unrivalled shipbuilding resources of Great Britain. Within a short period the country was put in a position to deal with the formidable menace of torpedo attack on its fleet, when in channel ports, which previously threatened its safety.

Submarines.

The construction of submarines in England had been intermittent and very limited in extent up to 1894. Four or five vessels of the

class had been built, the largest and best boats by Mr. Nordenfelt, from designs largely due to Mr. Garrett, who also undertook the superintendence of the trials. Greece and Turkey acquired the vessels as built, but the Admiralty did not make any purchases. Another submarine vessel built on the Thames attracted attention a few years earlier (1887). She was named the *Nautilus* and the writer had some personal experience of her qualities, not altogether satisfactory. No other vessels of that type were laid down; and, indeed, there was no feeling in favour of submarines in the British Navy ten years ago, although it was always held that, if the construction of the class was desired, there would be no difficulty in meeting requirements speedily. The principles of construction for the type were fully understood, and their moderate dimensions enabled the multiplication of any selected type to be rapidly accomplished; but there was no desire to adopt the system for the British Navy.

Steam Turbines for Ship Propulsion.

In January, 1894, the first steps were taken by Mr. Parsons and those associated with him, to apply his system of steam turbines to ship propulsion. The first trial of the *Turbinia* was made in November of that year. For fully two years the experiments with that notable vessel were continued, 31 trials being made, 7 different arrangements of propellers tested, and final success achieved with 3 turbines, each driving a shaft with 3 propellers on each shaft. It is impossible to speak too highly of the courage and skill displayed by Mr. Parsons in this enterprise, which ended in a little vessel of 100 ft. in length and 44½ tons displacement, attaining a speed of 34 knots. A new era was thus entered upon in ship propulsion, and although (owing to various accidental circumstances) the development of the system has been much delayed, the merit of the work done by Mr. Parsons, and the enterprise shown by the gentlemen who formed the original syndicate, are now beginning to have their full effect. This new departure was made concurrently with a remarkable development in the use of the "express" type of reciprocating engine in destroyers and small cruisers; but the advantages obtainable in the rotary type of engine were so great that there could be no doubt of the ultimate result of the contest,

especially in ships of the mercantile marine, which, from the conditions of their service, are constantly working at or about the maximum engine power. At full power the turbines have their greatest efficiency, and exceed the best reciprocating engines in economy of steam, whereas their relative economy diminishes as the development of power decreases, and at low powers, they become inferior to the reciprocating type.

The British Mercantile Marine in 1894.

The British mercantile marine was entering upon a period of expansion in 1894 after a year of unusually small production of new ships. From 1889 to 1892 the gross tonnage of ships launched per annum had been from 1 100 000 to 1 200 000 tons; in 1893 this total fell to about 836 000 tons, and in 1894 again rose to 1 046 000 tons.* The largest ships launched in 1894 were the *Caledonia* and *Norman,* about 490 ft. in length, 7 500 tons gross and 10 000 to 11 000 i. h. p. The largest sailing vessel launched was the *Pitlockry* of 3 100 tons gross. In 1894, 133 steamers were launched, ranging from 3 000 to 7 000 tons, as against 92 steamers of smaller size launched in 1893. This indicated a tendency to an increase in the size of individual cargo steamers. The largest vessels of that class on the British Register in 1894 were about 480 to 500 ft. in length and 8 300 to 8 700 tons gross. That year was also distinguished by the construction of five cargo steamers of the "turret type," the first of which had been built in 1892; but the largest of these was only 340 ft. in length and of 3 200 tons gross tonnage. One cargo steamer of 10 000 tons was building in 1894, and was launched in the following year. She may be regarded as the predecessor of the modern type of large dimensions which has since grown so much in favour with shipowners. On the Atlantic service the *Campania,* 600 ft. in length and of nearly 13 000 tons, had just commenced her service, and her sister ship, the *Lucania,* was completed. During 1894 the *Campania* proved herself capable of maintaining a speed of over 22 knots at sea, with about 30 000 i. h. p. Amongst cross-channel steamers of that date, those used on the service between Dover and Flushing were the fastest, reaching a speed of about 22 knots. They were about 340 ft. in length and of about 1 450

tons gross, developing over 8 000 h. p. on service. On the Dover-Calais route the largest vessels were about 325 ft. in length and of about 1 100 tons gross tonnage, with a speed of about 20 to 21 knots, obtained with 6 500 h. p. Very soon after steps were taken by the City of Dublin Steam Packet Company to construct 4 new vessels (the *Ulster* class) 360 ft. in length, of 2 600 tons gross, which obtained a trial speed of over 24 knots with 9 000 h. p. The United Kingdom still held the lead in regard to the speed and size of all classes of mercantile steamships, and maintained it up to 1898, when the North German Lloyds took the lead with the *Kaiser Wilhelm der Grosse,* nearly 25 ft. longer than the *Campania,* and nearly 2 000 tons greater in tonnage; the maximum speed on service being about half a knot faster than that of the *Campania* and *Lucania.* The *Oceanic* of the White Star Line was built almost concurrently with the German ship, and (as the writer has explained more fully elsewhere) the late Mr. Thomas Ismay decided that with then existing subsidies paid to British steamships, it was not possible to work such vessels at a commercial profit at higher speeds than that which had been decided upon for the German steamer. His view was that the least saving in time on the voyage to New York, which would be of practical value, was 12 hours; and that the consequent increase in size, cost, and working expenses could not be made in association with commercial success. It would have involved about 30% increase in power, and 20% on the coal bill, besides reducing the freight-earning power by about 40 per cent. Consequently, it was decided that, although the *Oceanic* was 60 ft. longer than the *Kaiser Wilhelm der Grosse* and of nearly 3 000 tons greater tonnage, the maximum horse-power should be only 27 000, corresponding to a speed of about 21 knots on service, and such a reserve of boiler power was provided as insured practical regularity in the period occupied by the voyage. It was no lack of enterprise on the part of Mr. Ismay and his associates which led to this decision, and the lead in speed was virtually handed over to the German lines, because there was then no inclination on the part of the British Government to give such substantial assistance toward the construction of vessels of exceptional speed as has been recently granted to the Cunard Steamship Company.

Twin-screws were coming rapidly into favour for merchant

steamers in 1894, their advantages having been demonstrated in warships of deep draught during the preceding twenty-five years. In 1878 the writer summarized the experience with twin-screws up to date and warmly advocated their adoption in the mercantile marine. Little was done, however, until ten years later, and the most notable departure was made when the *Teutonic* and *Majestic* of the White Star Line and the *Paris* and *New York* of the Inman and International Line were constructed (1888-89). Since that date the use of twin-screws in all classes of merchant ships has rapidly extended, and enlarged experience has emphasized their great superiority not merely as giving greater safety, but more efficient propulsion.

Materials of Construction in 1894.

Mild steel of the quality which the British Admiralty began to specify for warships in 1875, had practically superseded iron for all classes of ships long before 1894. In that year 98.6% of the new steam tonnage was built of steel, and only 1.2% of iron, the latter material being used chiefly for trawlers and very small vessels. A longer interval elapsed with merchant ships than with warships in making this change of material, partly because up to 1891, mild steel was dearer than iron of the qualities commonly used, and partly because there were lingering doubts as to the trustworthiness of steel and its relative corrosion in sea water. The Allan liner, *Buenos Ayrean,* had been built of mild steel by Messrs. Denny as early as 1879, and as experience increased, so the new material gained in favour. Its good working qualities, uniformity of strength, great ductility and excellent behaviour in cases of collision, grounding, and other accidents, all tended to establish it in favour, and experience up to date has been so satisfactory that there is, even now, no general desire to introduce any substitute for mild steel. The use of steel castings, instead of heavy iron forgings, for important parts of the structure such as stems, stern-posts, shaft brackets, rudder frames, began about 20 years ago; by the year 1894 they had come into common use. For warships with ram-stems, large rudders and out-board shafting, the use of steel castings has effected remarkable economies in both the cost and the time of manufacture. Enlarged experience has enabled man-

ufacturers to obtain castings of complicated and difficult sectional forms, tending to considerable reduction in weight and to improved fastenings and attachments to other portions of the hull. Looking back upon the history of this particular application of mild steel (in which, owing to the writer's association with the Elswick firm during the period, 1883 to 1885, he had an intimate personal connection), it is most singular to note how shipbuilders were for a considerable time prepared to condone or minimize defects in iron forgings; whereas in regard to steel castings they insisted upon severe tests and the most careful examination before acceptance. For example, if the falling tests regularly imposed upon steel castings had been applied to iron forgings, there can be no doubt that, in many instances, the latter would have utterly failed. But many of those who offered the most strenuous opposition to the use of steel castings, never suggested that iron forgings should be similarly tested. In passing it may be added that the work done by British investigators and manufacturers in recent years in the improvement of steel castings—a work in which Mr. Hadfield of Sheffield has borne a most distinguished part—appears to justify the hope that, in the future, it will be possible to substitute steel castings, subjected to a special heat treatment, for many portions of ship structures where steel forgings are now used. Here, indeed, is a field of promise which has long been in view, although its exploration has been deferred; and if the dream, that furnace treatment and chemical composition can be substituted for many mechanical processes of pressing or hammering, can be realized in practice, then great further economies of weight and cost should be possible.

Aluminum for Shipbuilding.

Prior to 1894 there had been discussions of the possibility of using other materials than steel in special classes of ships. Aluminum and its alloys found most favour, but the use of certain bronzes was also advocated. In 1892-93 two small aluminum launches were built at Zurich, and in 1894 another aluminum launch was at work on the Thames. In that year Messrs. Yarrow built a second-class torpedo boat of that material, and several yachts were similarly constructed. In all cases considerable economies of weights were

obtained, but the alloy used proved to be wanting in durability when exposed to the action of sea water. The broad conclusions reached on the basis of this experience were, that while pure aluminum had not the requisite strength, or working qualities, for the purposes of shipbuilding, the alloys obtained up to 1894 were wanting in durability. Messrs. Yarrow have not proceeded further with the system; nor has the French Navy continued to use it. It has been alleged, recently, that aluminum bronzes have been obtained, which combine ductility and good working qualities with non-corrodibility in sea water. It does not appear, however, that any extended use has been made of the material, but for internal fittings in ships, for some portions of the machinery and for superstructures there can be no doubt that, at least, in special classes of vessels, there may yet be a future for such alloys.

British Merchant Shipping in 1904.

The growth of the British mercantile marine, during the last ten years, has been both great and continuous, as will be seen from Table 1, furnished by the authorities of that great organization, "Lloyd's Register of British and Foreign Shipbuilding."

In 1903 there were launched 697 vessels of nearly 1 200 000 gross tonnage, and 41 warships of 152 000 tons displacement. At the close of 1902 the British Register contained 5 037 steamers of nearly 4 500 000 tons and 2 384 iron steamers of 1 120 000 tons. The total for the British Empire was 8 553 steamers of 14 193 000 tons; all other maritime countries combined owning 9 228 steamers of less than 13 million tons. Including sailing ships the total for the British Empire was 11 134 vessels aggregating over 16 million tons; all other maritime countries combined owned 18 809 ships with an aggregate tonnage of 17 637 000 tons. It is universally agreed, that in economy of first cost, and in speed of construction, British shipbuilding has a considerable advantage, due, no doubt, chiefly to the facts that Great Britain took the lead in the introduction of both iron and steam ships, and has had the advantage resulting from the training of two generations of skilled workers, and of the enterprise of shipowners and shipbuilders.

The growth in the size of individual ships during the last ten

years has been most remarkable. It has been stated, that in 1894 there was building only one ship of 10 000 tons, which was launched in the following year. Table 2 has been prepared by "Lloyd's Register," and gives the names of vessels of over 10 000 tons (gross) launched during the years 1894 to 1903.

TABLE 1.—VESSELS BUILDING IN THE UNITED KINGDOM ON THE 31ST MARCH IN EACH YEAR FROM 1894 TO 1904, INCLUSIVE.

(Warships not included.)

Year.	Steam.		Sail.		Total.	
	Number.	Tons (gross).	Number.	Tons (gross).	Number.	Tons (gross).
1894..	346	663 396	68	61 812	414	725 208
1895..	310	628 605	46	27 713	356	656 318
1896..	341	736 472	59	32 792	400	769 264
1897..	388	810 439	40	18 042	428	828 481
1898..	579	1 181 036	27	4 085	606	1 185 121
1899..	568	1 382 289	29	3 426	597	1 385 715
1900..	511	1 249 099	43	11 323	554	1 260 422
1901..	415	1 294 163	29	8 953	444	1 303 116
1902..	401	1 213 504	30	26 840	431	1 240 344
1903..	382	963 365	43	11 321	425	974 686
1904..	353	973 511	45	15 153	398	988 664

At the end of 1903 the largest vessel afloat was the *Baltic* of nearly 24 000 tons gross tonnage, which commenced her service in June, 1904. It is unnecessary here to explain the economic advantages attaching to increase in the size of ships, or its effect upon the cost of over-sea transport. But it may be interesting to state that, whereas in 1890, the average gross tonnage of British steamers (exceeding 100 tons) was 1 570 tons, in 1902 it was 2 200 tons. This average includes a large number of yachts, river and coasting steamers, and other vessels of less than 200 tons gross. In Table 3, prepared by "Lloyd's Register," the size of merchant and other vessels exclusive of warships launched in the United Kingdom during 1903 is indicated.

The mercantile fleets of the world, at the end of 1902, included 84 steel steamers of 10 000 tons and upward. Of these, 39 were owned by the United Kingdom, 26 belonged to Germany, 9 to the United States, and the remainder to France, Holland and Denmark.

At the same date there were 145 vessels of 7 000 to 10 000 tons, 109 belonging to the United Kingdom, 22 to Germany, and 7 to the United States.

TABLE 2.

Name.	Tonnage.	Year.	Name.	Tonnage.	Year.
Georgic	10 077	1895	*Celtic*	20 904	1901
Pennsylvania	13 333	1896	*Minnetonka*	13 398	1901
Cymric	13 096	1897	*Walmer Castle*	12 546	1901
Briton	10 248	1897	*Noordam*	12 531	1901
Medic	11 985	1898	*Rijordam*	12 527	1901
Afric	11 948	1898	*Athenic*	12 234	1901
Romanic	11 394	1898	*Haverford*	11 635	1901
Statendam	10 491	1898	*Merion*	11 621	1901
Oceanic	17 274	1899	*Cedric*	21 035	1902
Ivernia	14 058	1899	*Arabic*	15 801	1902
Saxonia	14 281	1899	*Carpathia*	13 564	1902
Minneapolis	13 401	1899	*Cretic*	13 518	1902
Saxon	12 385	1899	*Corinthic*	12 231	1902
Persic	11 973	1899	*Ionic*	12 232	1902
Winifredian	10 405	1899	*Hellig Olav*	10 085	1902
Bavarian	10 387	1899	*Baltic*	24 000	1903
Minnehaha	13 403	1900	*Republic*	15 378	1903
Suevic	12 500	1900	*Kenilworth Castle*	12 975	1903
Runic	12 482	1900	*Armadale Castle*	12 973	1903
Canopic	12 097	1900	*Slavonia*	10 606	1903
Vaderland	12 018	1900	*Macedonia*	10 512	1903
Zeeland	11 905	1900	*Marmora*	10 509	1903
Tunisian	10 576	1900	*United States*	10 095	1903
Devonian	10 418	1900			

TABLE 3.

Tonnage.	Steam.	Sail.	Tonnage.	Steam.	Sail.
Under 50 tons	5	5	6 000 to 6 999 tons	9	..
50 to 99 tons	48	2	7 000 to 7 999 tons	12	..
100 to 199 tons	116	31	8 000 to 8 999 tons	1	..
200 to 499 tons	113	17	9 000 to 9 999 tons	3	..
500 to 999 tons	45	5	10 000 to 11 999 tons	3	..
1 000 to 1 999 tons	92	5	12 000 to 14 999 tons	2	..
2 000 to 2 999 tons	52	1	15 000 tons and above	4	..
3 000 to 3 999 tons	77	..			
4 000 to 4 999 tons	45	..			
5 000 to 5 999 tons	5	..	Total	632	65

The great cargo steamers, with enormous carrying capacity, can be profitably worked at low rates of freight, and enable transport over-sea to be conducted with remarkable economy. In the writer's Presidential Address at the Institution of Civil Engineers he gave many illustrations of these facts, showing that the cost of fuel per

thousand ton-miles has been reduced to 2½ to 3 pence, and that in the White Star Steamer *Suevic* an expenditure of about 3 shillings on coal drives a ton weight from England to Australia. The *Ivernia* and *Saxonia* of the Cunard Line exceed 20 000 tons in displacement, and steam 15½ knots on 140 tons of coal a day. The cargo steamer, *Monarch*, carrying 11 600 tons dead weight, averaged over 11 knots on two Atlantic voyages, burning about 48 tons per day. The outward voyage was in ballast; on the homeward, she was fully laden. "Quick despatch" in loading and discharging these enormous cargoes is essential, as the stay in port must be minimised, if the best economic results are to be obtained. By the aid of mechanical lifting appliances a mixed cargo of 11 000 tons dead weight can be discharged in 66 hours. In no department of ship equipment has greater advance been made than in the device and construction of these lifting appliances. Careful organisation is required also for the collection and warehousing of the cargo, in order to shorten the period of stay in port. As an example of what can be done, it may be stated that an excellent authority recently gave 25 to 30 shillings per ton as the cost of conveying ordinary cargo from the United Kingdom to Bombay, which is about one-thirty-fifth of the average cost of transport of goods by railway in the United Kingdom.

On June 30th, 1904, there were 361 merchant ships under construction in the United Kingdom. Of these, 132 were less than 1 000 tons, 70 from 1 000 to 3 000 tons, 137 from 3 000 to 6 000 tons, 11 from 6 000 to 9 000 tons, 4 from 9 000 to 12 000 tons, and 7 more than 15 000. It will be seen, therefore, that while the average dimensions of ships are increasing, and a larger number of ships are built of extreme dimensions and tonnage, use can still be found for great numbers of cargo steamers of moderate size. The supreme position of the British mercantile marine is due chiefly to its development of cargo steamers; and (to quote the writer's own words) "the largest share of the work of the world in over-sea transport is still done by the much-despised 'tramp' steamer." By close study of requirements, and successive improvements made by shipbuilders, engineers and shipowners, wonderfully economical results have been achieved. For example, a vessel about 360 ft. long, 47 ft. broad, 30 ft. deep and drawing 24 to 25 ft. when loaded, can carry

6 500 tons dead weight, and steam at 11 knots with a consumption of 27 tons of coal *per diem*. The cost of fuel per thousand ton-miles is less than 3 pence, and under the present conditions of the shipbuilding trade the first cost would be about £40 000. When such economy is realised in steamships, which secure greater speed and regularity of service, it is no wonder that they are gaining upon sailing ships even for the longest ocean voyages.

Sailing ships have been continuously diminishing in importance during the last ten years. In 1903 only 65 sailing vessels of 25 000 tons gross were launched in the United Kingdom. Under modern conditions steamships are reckoned, for commercial purposes, as equal to four or five times their tonnage in sailing ships; and as the mercantile marine of the United Kingdom contains so small a proportion of sailing ships, in comparisons of efficiency or carrying capacity, these circumstances must not be overlooked. There is a keen desire on the part of British Shipowners to keep abreast of the necessities of traffic, and to secure the greatest possible economy, which leads them to substitute new for old ships long before the latter are worn out. In 1902, for example, about 320 000 tons of British ships were sold to foreign owners as against purchases of 65 000 tons. The sailing tonnage of the United Kingdom decreased by about 92 000 tons in 1903, while the steam tonnage increased by 497 000 tons, and the net increase of British tonnage, during 1903, amounted to 405 000 tons. The net increase of the world's tonnage, in 1903, was 1 402 000 tons, steam tonnage being increased by 1 545 000 tons, while sailing tonnage was diminished by 143 000 tons.

The *Baltic* is the first modern steamship exceeding the *Great Eastern* in length between perpendiculars, displacement and tonnage, but she is inferior to that ship in breadth and moulded depth. She is 710 ft. between perpendiculars, and about 726 ft. in length over all, 75 ft. beam, 49 ft. moulded depth, with engines developing 13 000 to 14 000 h. p. and a speed of 16 to 17 knots on service. At 32-ft. draught she displaces 34 000 tons, and if depth of water were available, she could be safely loaded to 37 or 38 ft., the displacement being then over 40 000 tons. She can carry 3 000 passengers in addition to her crew of 350 officers and men, and her cargo capacity is enormous. To deal rapidly with this cargo, she is fitted with very powerful and numerous lifting appliances. In

this latest example of the intermediate class of passenger and cargo steamer with moderate speed is to be found an epitome of the progress made in shipbuilding and engineering during the half century which has elapsed since Brunel commenced his studies for the *Great Eastern,* and the genius of the great engineer stands out the more clearly as the comparison between the two vessels is completed. Considering the date and circumstances of her construction, the *Great Eastern* is still the most remarkable vessel ever completed, although she is no longer the largest.

Hitherto the "intermediate" class of passenger and cargo steamer has not exceeded 15 to 16½ knots in speed, but in the *Caronia* of the Cunard Line, launched in July, 1904, a new departure has been made, and a service speed of 18 knots has been decided upon. Her dimensions are not so great as those of the *Baltic.* She is about 48 ft. shorter and 3 ft. narrower, her gross tonnage is 3 000 tons less, and her displacement at 32 ft. about 30 000 tons, 4 000 tons less than that of the *Baltic.* Her total accommodation is for 2 650 passengers and 450 crew. The engines are to develop over 20 000 h. p., or fully 50% more than the power in the *Baltic.* The dead-weight capacity is 12 000 tons, considerably less than that of the *Baltic.* A sister ship of the same size, but with turbine engines, is also in hand. They are interesting vessels, standing midway between the previous intermediate steamers and the *Oceanic* of the White Star Line, which is about 27 ft. longer, 5 ft. narrower, and about 2 000 tons less displacement, but has engines of one-third greater power, and a sea speed of nearly 21 knots. The *Oceanic* has quite exceptional cargo capacity for an Atlantic liner, but is necessarily inferior in that respect to an intermediate steamer (like the *Cedric*) of about the same dimensions with half the engine power, and 4 to 5 knots slower.

The *Kaiser Wilhelm II* slightly exceeds the *Oceanic* in dimensions, but is of much greater gross tonnage (20 000 against 17 270 tons). Her load draught is less, but at the same draught the two vessels would have approximately equal displacements, say about 26 000 tons at 29½ ft. The German ship has engines of 50% greater power and is from 2½ to 3 knots faster. Her dead-weight capacity is, therefore, much less, while her coal consumption is much greater, and she can carry very little cargo as compared with the *Oceanic.*

These are interesting illustrations of the widely different distri-

butions required with practically the same displacement in order to fulfill varying conditions of speed and carrying power or accommodation. To the naval architect the close study and careful analysis of examples in past practice are full of interest, and conducive to progress in later designs.

The designs of the new Cunard steamers, which are to be capable of maintaining a speed exceeding that of the fastest German ships by at least a knot, furnish the latest illustration of the great increase in size and cost which accompanies increase in speed. They will be 760 ft. long between perpendiculars, 88 ft. broad, and over 60 ft. moulded depth. Accommodations will be provided for nearly 3 000 persons. To secure the intended speed the engine power will have to be about 70% greater than that of the *Kaiser Wilhelm II,* and the corresponding increase in coal consumption will make such large demands on the dead-weight capacity, that a very moderate amount of cargo will be carried. In the agreement with the British Government it is contemplated that each of the two ships will cost £1 300 000. The use of steam turbines instead of reciprocating engines, and of four shafts and propellers, involves an experiment of great novelty; but it has been undertaken after full enquiry, and promises to be successful, while its potential advantages are very considerable.

Special Classes of Cargo Steamers.

The last ten years have been marked by considerable specialization in designs for steamers, in order to adapt them for the conveyance of various descriptions of cargo, or to secure other advantages. Side by side with this specialization has proceeded the development of the "tramp" steamer, which "seeks" for cargoes in all quarters, and generally manages to accommodate any cargo that offers.

Oil-Tank Steamers.—Among these special types oil-tank steamers stand prominent. Eighteen years ago only ten steamers carried oil in bulk on over-sea voyages, and these vessels were of moderate size, not exceeding 240 ft. in length and 1 500 tons (gross). In 1902 there were nearly 200 tank steamers, many of large size. The largest is 512 ft. long, of 21 000 tons load displacement, fitted to carry 11 000 tons of oil in 16 tanks, and capable of carrying 12 500 tons

dead weight. The maximum speed is 14 knots. In the design of these vessels difficult problems have to be solved in regard to subdivision, stability and strength of structure, in consequence of their liquid cargoes. In working them, remarkable results have been achieved, in the direction of adaptability for general cargoes when oil is not carried.

Meat Carriers.—These steamers form another group which has been greatly increased in size and number. About 160 vessels of this class are now employed in the carriage of frozen meat. They are fitted with powerful refrigerators, and built with elaborate arrangements for the insulation and ventilation of storage chambers. The largest vessels approach 500 ft. in length, with dead-weight capacity of 10 000 tons, and each can carry 100 000 carcases. It is estimated that in the aggregate this section of the mercantile marine can carry from 9 million to 10 million carcases.

Ore Carriers.—Vessels of this type, of great size, have also been built with special means for shipping and discharging cargoes. The *Grangesburg* is the most notable of these, having been completed in 1903. She is of the "turret type," 440 ft. long, 10½ knots speed, with about 10 000 tons dead-weight capacity. She has 24 derricks carried on 7 pairs of masts, and 12 large hatchways. The whole cargo can be discharged in 35 hours. And it is stated that she will carry and discharge over 200 000 tons of ore per annum in her service between Sweden and Rotterdam.

Cable-Laying Steamers.—These steamers date from 1874 when the *Faraday* was specially built for this service. Her length is 360 ft.; breadth, 52 ft.; and gross tonnage, 4 900 tons. She can carry 4 300 tons cable, and nearly 1 600 tons of coal and stores on 26 ft. draught, the speed being 8 to 9 knots. The largest cable-laying ship on service at present is the *Colonia* (built in 1902), her length being 487 ft.; breadth, 56 ft.; 8 000 tons gross, with speed of 12 to 13 knots. On her first voyage while laying the Pacific cable, she carried over 3 500 miles of cable, weighing nearly 7 700 tons, besides coal and stores, on 26-ft. draught. On the voyage she steamed over 3 400 miles and consumed nearly 9 000 tons of coal in 5 months and 10 days. The cable was "paid out" at the rate of 210 miles per day, the maximum depth of water on the route being 3 400 fathoms.

Turret-Type Steamers.—Of the many special forms of cargo

steamers proposed or built in recent years the "turret type" originated by Messrs. Doxford has found most favour; that firm has constructed a hundred ships, and similar vessels have been built by other shipyards. The latest for general trade is 390 ft. long, 5 500 tons gross, and carries nearly 9 000 tons (dead weight) on 24-ft. draught at 10 knots, with less than 2 000 h. p. The American "whale-back" is the progenitor of the "turret type."

Single-Decked Steamers.—Vessels of this type of large size have also been recently constructed, special arrangements being made to ensure rigidity in the structures. Vessels of this class carrying 6 000 tons dead weight are on service, and others capable of carrying 12 000 tons have been designed but not yet built.

Materials and Methods of Construction in 1904.

Up to the present time mild steel holds its own, and there is no marked or general desire to use stronger steel, or to introduce other materials. Experiments made under the writer's direction more than 25 years ago showed that it was possible to obtain steel plates, bars and rivets having an ultimate tensile strength of 38 to 40 tons per sq. in., with good ductility and satisfactory working qualities, if it were found desirable to use such material; but hitherto considerations of durability and stiffness have determined the lower limit of scantlings in most ships, and mild steel has met all requirements As dimensions and engine powers of warships have been increased, however, recourse has been had to stronger steel, beginning with torpedo-boat destroyers. Similar material has also been specified by the writer for important portions of the structures of large warships since 1898. In small cruisers it has been extensively used. With this stronger material it is found desirable to drill the holes, but no other special treatment is necessary. The gain in strength, measured by the comparative elastic limits, is from 20 to 25% over that of mild steel in the material which has so far been used by the British Admiralty. It is most important, in specifying for the stronger steel, to define the elastic limit, and to ensure its existence by suitable tests, if full advantage is to be secured.

Admiralty practice has always left manufacturers free in regard to the chemical composition of the material; but the use of open-

hearth steel (either acid or basic) is insisted upon for all important parts of the structures of ships. Recent experiments have shown that, so far as plates and bars are concerned, it would be possible, with certain qualities of nickel steel, to obtain still greater strength with good working qualities. It does not appear, however, that proof has been given hitherto that rivet steel of the same quality could be readily worked, or that entirely satisfactory joints could be made in the combinations of plating forming the shells and decks of ships. This is a most important point, and is sometimes overlooked in recommendations of the use of material of high tensile strength. When stronger steel is used, modified structural arrangements are undoubtedly of great importance; because, as the thicknesses of plates and bars are reduced, there is a greater liability to buckling under compressive strains. As regards corrosion, the use of high percentages of nickel would probably furnish the necessary durability, even for very thin plates; but, with reduced scantlings, the provision for ready means of access for examination, cleaning and painting, are obviously of great importance. The danger of failure by buckling has been shown to be considerable (unless met by proper structural arrangements and stiffening) in many light draught vessels when making over-sea passages to their regular stations. In later years, further illustrations of the necessity for precaution have been afforded in torpedo-boat destroyers. It need hardly be said that recognized principles of construction make it obvious that, in order to secure the best association of lightness and strength, stiffness should be obtained wherever possible by suitable structural supports to thin plates rather than by increased thicknesses in the plates themselves. In many instances, however, this fundamental principle of construction is overlooked, and unnecessarily heavy scantlings are insisted upon, or unwise additions to structure made when signs of weakness are discovered.

During the last ten years no marked advance has been made in our knowledge of the scientific principles on which estimates for the structural strength of ships are based; but very much has been added to available data by the widened application of methods of calculation and comparison, for which we are largely indebted to the late Professor Rankine. In that admirable work, "Shipbuilding, Theoretical and Practical," to which he made most valuable con-

tributions, Rankine not merely indicated general procedure, but gave illustrative examples of methods of computing bending moments and sheering stresses, and regulating the longitudinal and transverse strength of ships. Mr. William Froude also dealt with this branch of naval architecture in a masterly and suggestive manner. Later investigators have advanced the investigation, particularly in connection with the transverse strength of ships, and the effects of rolling and pitching motion upon stresses borne by ships' structures. The *Transactions* of the Institution of Naval Architects contain the most valuable contributions to such knowledge. After making allowance for all that has been done in this direction, it still remains true—and, from the nature of the case, will probably always remain true—that the safest rule for naval architects is to base scantlings for new vessels upon comparisons with other vessels with which experience in actual work has been gained. Such comparisons must rest upon thorough analysis of all features in the problem which admit of exact treatment, and due allowance must be made for differences in forms, dimensions and lading. Careful study of cases of partial failure, exceptional straining or other misfortunes to ships, frequently furnish valuable information for guidance in future design, although, to individuals, they may be unpleasant and troublesome. Increase in the speeds and dimensions of ships has introduced many new conditions, and in some instances, there have been indications of local or general weakness requiring modifications of structures; but, in proportion to the strides that have been made during recent years and the departures from precedent, cases of serious general structural weakness have been neither numerous nor costly. No doubt, we are still imperfectly informed as to the actual margin of strength existing in many structures, and it cannot be asserted that accepted systems of construction embody the best conceivable distribution of material for the association of lightness and strength. Brunel, in a famous passage of his notes on the *Great Eastern,* laid down the true principle of construction when he said that "no materials should be employed on any part except at the places, and in the direction, and in the proportion in which it is required, and can be usefully employed for the strength of the ship; and none merely for the purpose of facilitating the framing and first construction." This broad generalization is often

overruled in practice by the desire to secure greater economy or rapidity in building, or by considerations of a practical nature involving accommodation, cargo-carrying power or facilities for working cargo. In warships, in particular, considerations of armament and protection often interfere radically with arrangements which, from the point of view of strength of structure, would be preferred. The installation of enormous engine power also introduces local conditions of an important character which cannot be disregarded. After making allowances for all these circumstances, the writer is disposed to believe that Brunel's principle could, with advantage, be more largely applied in ship construction than it has yet been; and the matter is one which must be dealt with courageously if full advantage is to be taken of the superior qualities and forms in which materials for shipbuilding can now be obtained.

Improvements in Marine Engineering.

Since 1894 there have been many improvements in the propelling apparatus of ships, tending to economies in weight and coal consumption. It would be out of place to enter into any detail of these, but they so greatly influence ship design that a brief reference must be made to the main lines of advance. From 1891 to 1901, it has been estimated by high authorities that for British mercantile steamers the average steam pressure rose from about 160 to 200 lb. per sq. in; the average revolutions from about 64 to 87 per minute; the average piston speed from about 530 to 655 ft. per minute; and, the average coal consumption changed from 1.75 to 1.5 lb. per h.p-hr. on prolonged sea voyages. With cylindrical boilers (tank type), which are universally used for merchant ships, 220 lb. per sq. in. is the maximum pressure adopted, and many engineers prefer to use a somewhat lower pressure. Steamers of high speed have higher rates of revolution, the piston speeds on service being 900 to 1 000 ft. per minute. There is a consensus of opinion in favour of retaining long strokes in fast ocean steamers.

Warships are engined on a different system, largely because they ordinarily cruise at low speeds and rarely steam at maximum powers. Shorter strokes and higher rates of revolution are adopted, with greatly lessened weights, in proportion to maximum power and large

economy of space. For battleships, 100 to 110 revolutions and piston speeds of about 900 ft. per minute are used; for large cruisers, 120 to 140 revolutions and 1 000 ft. piston speed; for small cruisers, 220 revolutions and 1 000 ft. piston speed; for destroyers, 350 to 400 revolutions and up to 1 200 ft. piston speed.

Water-tube boilers are now universally adopted for all classes of British warships, with steam pressures of 250 to 300 lb. The long-continued controversy on this subject has not ended; but enlarged experience has led to great improvements, and with recent types of boilers greater endurance and economy in coal consumption have been secured. The Belleville type has recently given better results, and there are many advocates of its extended use in British warships. The Advisory Committee appointed by the Admiralty do not favour this policy; and on their recommendation the three types used at present for large ships are the Yarrow (large tube), Babcock and Wilcox, and Niclausse. As a temporary expedient, and to secure economy of coal consumption at cruising speeds, the Committee recommended the use in large ships of a small number of tank boilers in association with water-tube boilers. Personally, the writer never favoured such a combination. It has been largely used in Germany. As was anticipated, it has been abandoned almost before the first examples were tried, the economy of coal consumption with recent water-tube boilers having proved greater than that of their predecessors.

With water-tube boilers in British warships open stoke-holds have been adopted, in association with powerful fans. In merchant ships some system of forced draught is largely used, that introduced by Mr. Howden finding most favour.

In the smaller classes of cruisers and vessels of the torpedo flotilla, water-tube boilers, with tubes of small diameter, and machinery of the "express" type are necessarily adopted. The latest and largest application of this system is in the "scouts" now building. These vessels (360 to 370 ft. long and about 2 900 tons displacement) are to have engines of 16 000 to 17 000 h. p., driving twin-screws. The *Novik*, of the Russian Navy, is very similar, but she has three screws. Great interest attaches to the trials of these vessels, particularly in regard to the utilization of their great power and the management and endurance of the engines. In such installa-

tions, closed stoke-holds and high forced draughts are adopted. Recent trials have shown remarkable economy in coal consumption of destroyers, in association with moderate forced draught. Messrs. Yarrow have obtained, or exceeded, the full contract speed in some instances with less than 2 in. of water as the air pressure in stoke-holds, and about 1.6 to 1.7 lb. of coal per h.p-hr.

Steam Turbi-Motors.

The practical application of steam turbines to ship propulsion, especially by Mr. Charles Parsons, has been delayed by various accidental circumstances, and partly by the necessity for solving many new problems. Encouragement was given by the Admiralty to the new system, immediately after the *Turbinia* had been made successful, by ordering the destroyer *Viper*. This encouragement has been continued, not merely by ordering other destroyers similarly engined, but by extending the system to the *Amethyst,* a third-class cruiser, 360 ft. in length, and 3 000 tons, with engines of about 10 000 tons. This was the writer's last design of a small cruiser for the Royal Navy, and he recommended the use of turbines. Her trials are now about to be undertaken, and will be of great interest. If they prove successful (of which there can be no doubt), it may be anticipated that the Admiralty will apply turbines to much larger vessels.

Meanwhile the greatest experience has been gained with passenger steamers employed on cross-channel or coast service. Messrs. Denny showed the way with the *King Edward* for the Clyde, and the *Queen* for the Dover-Calais route. Now a large number of similar vessels are built, or building. Several yachts have been fitted with turbines. One of the latest of these was designed by the writer for Sir George Newnes, the turbines being specially arranged to give economy of steam at cruising speeds, which will be accompanied by the development of about 50% of the full power.

On the whole, experience with turbine machinery has been satisfactory, and its advantages in regard to freedom from vibration, reduced cost of working, maintenance and supervision, and diminished space and weight have been conclusively demonstrated. As to economy in the use of steam as compared with the best types of reciprocating engines, the most trustworthy information has been

obtained in electric generating stations on land, where it has been proved that turbines are much superior at full power, about equal at 70% of the full power, and inferior to reciprocating engines for smaller percentages. Mr. Charles A. Merz, of Newcastle-on-Tyne, has probably made the most complete experiments on this matter, comparing reciprocating engines of high efficiency with turbines. As a result he has adopted turbines exclusively in his latest and largest generating station. Another fact, experimentally demonstrated, is that as the size of turbines increases so their relative economy is improved.

No doubt in destroyers and small vessels fitted with turbines it has been found that at low cruising speed and with small powers—not exceeding 10% of the maximum—the reciprocating engine has given much greater economy than the turbines actually fitted. This feature of turbine machinery is especially important for warships, and is receiving close attention from Mr. Parsons and other engineers. Already modified arrangements of turbines and combinations of reciprocating engines and turbines, are being tried. One of the most interesting experiments in this direction is that of Messrs. Yarrow, wherein a central reciprocating engine is associated with two turbines, each of the three developing about the same power at full speed, while at cruising speeds the central engine is used for propulsion. In the *Amethyst* this matter has been specially dealt with, and the comparative trials of that vessel alongside of sister cruisers with reciprocating engines will be of great interest and value.

Three or four shafts have been used in most of the turbine steamers, three, as a rule, being preferred. It is well known that, under the new conditions of extremely rapid rotation, the selection of the most suitable propellers has been a matter of great difficulty. In the *Turbinia* this was especially true, and Mr. Parsons showed the greatest courage and ability in the various modifications by which he achieved ultimate success. Very much remains to be done in this direction, and experiment alone can furnish the best solution. Reversing arrangements were not fitted in the *Turbinia,* but are essential to maneuvering power, and are now universally adopted. In some cases it appears that somewhat greater power in the revers-

ing turbines would be advantageous. This is a detail easily dealt with when requirements are clearly stated. Of course such additional reversing power involves greater weight. In the *Turbinia* an extreme example was given of what the system could produce in regard to the proportion of weight to power. Subsequent experience has tended to lessened rates of revolution, increased reversing power, and other modifications tending to increase of weight. It is, however, undoubtedly true that turbines are relatively lighter than reciprocating engines. Messrs. Denny estimate that if the turbine steamer, *King Edward,* had reciprocating engines instead of turbines (the same boilers remaining), the speed would be reduced from 20.5 to 19.7 knots, corresponding to 20% difference in power.

In ocean-going passenger steamers built to work regularly at full power many of the difficulties above mentioned do not occur. The occasions are few, and not of long continuance, where the engines are worked at low power. Consequently the turbine system, for equal speed, should have a two-fold advantage, *viz.,* by reason of the less weight in proportion to power, and the more economic use of steam. On these points actual experience will soon be gained with the two turbine steamers now building for the Allan Line. They are 520 ft. long between perpendiculars and about 12 000 tons (gross). The boilers are capable of supplying steam for 11 000 h. p. with reciprocating engines. There are three shafts, each driven by a turbine and carrying a propeller of small diameter. The average speed in moderate weather is to be 17 knots, but a higher speed should be readily obtained. An interesting comparison may be possible between the performances of these vessels and those of the *Moldavia* class of the P. and O. Line which are very like in dimensions and power, but fitted with twin-screw reciprocating engines of the most modern type.

The decision to adopt the steam-turbine system in the new Cunard steamships has aroused much interest, and surprise has been expressed in some quarters that an experiment of such magnitude should have been undertaken. It is, however, well known, that before reaching that decision the Chairman and Directors appointed a strong and representative Committee, who thoroughly investigated the matter experimentally and scientifically. The

report of that Committee has hitherto been treated as confidential by the Cunard Company, and any publication on the subject has been unauthorized and incomplete. As a member of the Committee, and as Consulting Naval Architect of the Shipbuilding Company, which is responsible for the design and construction of one of the vessels, the writer is fully informed, but not at liberty to enter into details. One point, however, may be dealt with as of general interest. Those who consider the course taken to be doubtful, naturally dwell upon the fact that, at one stride, an advance is to be made in the power of the turbines (as compared with the largest engines of that class yet fitted in any ship) fully as great as that which has been made, by successive steps, with reciprocating engines in the last forty-five years. It cannot be questioned that this great stride involves certain difficulties, particularly in the design of details and the conduct of manufacture. Nor is there any doubt but that experience—with its processes of trial and error, and its suggestions for successive improvements—is of immense value, when it is possible. This is the policy recommended by the writer for the Royal Navy and adopted by the Admiralty for turbine-propelled vessels. But the case of the Cunard steamships was altogether special. In order to obtain the desired speed an increase of at least 70% of engine power was required over that of the swiftest and most powerful existing Atlantic liner. As a consequence triple-screws would have become necessary; and, even then, each engine would have largely exceeded in power any previous twin-screw engine, while there would have been little experience to go upon in designing efficient propellers, and these, with the reciprocating type of engine, would have been of great diameter. Moreover, the installation of three sets of machinery would have involved considerable difficulty, and one set would necessarily have been placed far aft where the danger of serious vibration, even with the best-balanced design possible, would have been great. Altogether it is certain that, if reciprocating engines had been used in these vessels, many experimental features would have been introduced, and some of these involved serious risks and drawbacks. These considerations are undoubtedly weighty, but they have been overlooked in some criticisms.

One incidental result of the use of quick-running steam turbines has been the extended use of triple- and multiple- screws, and the enlargement of experimental data in that direction. The writer's opinion in regard to triple-screws as compared with twin-screws, when reciprocating engines are used, is well known, and need not be restated. But with turbines the conditions are altogether different. Triple-screws become a necessity in most cases, and in the Cunarders, quadruple-screws were the best solution of the problem, having regard to engine design and propeller efficiency. The small diameters of screws possible with quick-moving turbines give great advantages, including deeper immersion, less probability of racing and less "augment" of tow-rope resistance. Naturally experience alone can decide what is the best form and area of blades that can be adopted for each design; and it may well happen that in this particular the first trials may suggest the possibility of improvement in pitch ratio, or in blades. This is quite a common experience now when unprecedented speeds are attempted, and all that can be done in either case is to take all possible advantage of previous experience in designing new propellers. It need hardly be added that this has not been overlooked in the Cunard designs.

Internal Combustion Engines.

In common with France and the United States, Great Britain is rapidly developing the construction of oil-motor launches of great speed, and the possible application of internal combustion engines, on a larger scale, to ship propulsion, is receiving attention. Messrs. Thornycroft have designed machinery of this class for a torpedo-boat destroyer of 6 000 h. p., the piston speed being the same as with steam engines. The space occupied by the new type is only about 60% of that required by steam engines and boilers, and there would be large savings in weight. This can only be regarded as a sketch design, as it goes very far in power beyond any actual installation, but it is suggestive. For British submarines Messrs. Vickers have made engines up to 300 B. h. p. and the Daimler Company has made engines of equal power. In the small swift launches so far built, it is claimed that the propelling apparatus

and fuel for six hours weigh only from one-sixth to one-tenth as much as for a good condensing steam engine and boiler, suitable for boats and capable of developing the same power. There is a great saving in space occupied by propelling apparatus, a large increase of accommodation, and much enlarged power of covering distance. In a good steam engine fitted in boats from 2 to 2½ lb. of coal per horse-power-hour are consumed; with oil about one-third that weight suffices.

Besides oil engines and spirit engines, gas engines (using gas made from solid fuel by "producers") are under consideration for marine purposes. The boiler and its contained steam and water would disappear in favour of producers, cheaper qualities of coal would suffice for making gas, and it is anticipated that large economies in cost, as well as weight and space, would be effected. Practical steps are being taken to give effect to this idea.

Claims are also made that gas turbines will be brought into use, and the writer has had statements made to him recently that engines of this class of considerable size have been made and worked. As yet, however, there seems no sufficient evidence that the great difficulties inherent in the system have been overcome.

Oil Fuel.

British experience with oil fuel as a substitute for coal has not equalled that of oil-producing countries. Experiments have been made, however, on a considerable scale for marine purposes; the Admiralty having recently resumed the investigation which was begun many years ago and then suspended, while many merchant ships have been fitted for oil fuel. Satisfactory arrangements for efficiently burning oil fuel are now available for British ships, and every one recognizes the enormous saving on shipping oil and transporting it to the furnaces, as well as the advantages obtainable from its greater calorific value. The practical difficulty in Great Britain, however, and probably the crucial point in all countries, is that of adequate supplies of oil at reasonable prices. Statements have repeatedly been made that this difficulty has been overcome, but it remains as real now as it was ten years ago. Coal is holding its own for ship propulsion except in a few special trades.

British Warships in 1904.

The latest type of battleship for the Royal Navy, of which the first examples are now approaching completion, is the *King Edward* class, designed by the writer in 1901. These vessels are 425 ft. long, 78 ft. broad and 16 350 tons displacement. Their engines develop 18 000 h. p., and the guaranteed speed was 18½ knots for 8 hours. The first vessel tried (the *Commonwealth*) was ballasted to about 2 in. deeper than the designed draught of 26 ft. 9 in., and with 18 500 h. p., she exceeded 19 knots. On a thirty-hour trial, with 12 770 h. p., she attained 17.9 knots, and the coal consumption was 1.68 lb. per h.p-hr. The disposition of armour differs from that of the *Majestic* of 1894 in many respects. The after-end of the armoured citadel wraps round the base of the after-barbette, as in the *Majestic,* and the top of this armour is at the level of the main deck; but this depth of armoured side (about 14½ ft.) is continued to the bow, maintaining its full thickness until the fore-barbette has been passed, and then being gradually diminished to 3 in. at the stem. Abaft the citadel the water-line region is protected by thin side armour. There are two protective decks: one, nearly horizontal, about 9 ft. above water, and the other, curved transversely (as in *Majestic*), reaching to the lower edge of the side armour. The four 12-in. guns are mounted in pairs in barbettes and carried on revolving turn-tables with armoured shields. Between the barbettes, on the main deck, is a central battery with 7-in. armour on the sides, containing ten 6-in. quick-firing guns. On the upper deck, four 9.2-in. guns are mounted in four separate turrets. The side armour is 8 and 9 in., the barbette armour, 12 in.; the total weight of armour and backing is 4 800 tons. All the armour is of Krupp quality. The new feature in the armament is the use of 9.2-in. guns to supplement the 6-in. guns; a change rendered necessary by the fact that improvements in armour manufacture had made the protection given to secondary armaments in recent battleships superior to the penetrating power of 6-in. guns at the long ranges now adopted. Since the writer's retirement three other vessels have been ordered from this design, so that there are now eight of the class building. The hull costs about £400 000, and the armour about the same amount. Propelling and other machinery cost nearly £220 000; gun-

mountings and torpedo tubes, £215 000; and the total cost per ship exceeds £1 337 000, exclusive of armament and ammunition. Fully equipped, each ship represents over 1½ millions sterling.

The interval of ten years has raised the displacement of a first-class battleship from 15 000 to 16 350 tons and the cost from £820 000 to £1 337 000, excluding armament. The speed has been increased more than a knot, and great improvements have been made in armour, guns and gun-mountings; the defensive and offensive power being considerably increased.

These features of change in design extend to all classes of modern warships, but it is not possible to illustrate the tendency by references to many classes. Taking armoured cruisers, the *Drake* may be contrasted with the *Powerful*, a protected cruiser of 1894. They are practically of the same length, breadth and displacement; and, as both classes were designed by the writer, it is obvious that personal skill had nothing to do with the result. Owing to changed conditions, it was desired, in the *Drake*, to develop armour protection, to increase speed and to make the armament more powerful as compared with her predecessor. This involved a redistribution of the weights making up the displacement. By changes in freeboard and in superstructures, the abolition of the heavy and costly wood and copper sheathing, which had been thought necessary in the *Powerful* for her special service, and the acceptance of less thicknesses of deck protection, a considerable saving in weight was effected. With the weight thus saved it was possible to give the *Drake* 6-in. side armour and 5-in. casemates and shields; to increase the armament by two 6-in. guns; and to add about 36% to the engine power, with a gain of fully a knot in estimated speed. On the other hand, the maximum coal capacity was reduced from 3 000 to 2 500 tons. The *Drake* class cost rather more than one million sterling, exclusive of armament, the armour representing a considerable proportion of the total, and the more powerful engines involving large outlay. The *Powerful* cost less than £700 000; the only thick armour carried was that on casemates and shields, and the protective deck was comparatively inexpensive.

Of the numerous classes of cruisers, both armoured and protected, which now form part of the Royal Navy, it is impossible to

speak on this occasion. New developments are continuously taking place, amongst the most notable in recent years being the construction of a great flotilla of destroyers and a few "scouts," to which reference has been made previously. Submarine vessels of the Holland type have been added to the fleet, and auxiliaries to fleets—repair and depôt ships, water tanks and colliers—have been built, or are contemplated. According to the latest Parliamentary Returns, on March 31st, 1904, the British Navy included the following vessels, built and building, or to be commenced in 1904: Battleships, 67; coast-defence ironclad, 1; armoured cruisers, 45; protected cruisers and "scouts," 116; unprotected cruisers, 8; torpedo vessels, 32; destroyers, 160; torpedo boats, 91; submarines, 29; a grand total of 549 vessels.

The examples above given for certain classes explain the enormous increase of expenditure on war fleets which has occurred in recent years. The reconstruction of the Royal Navy, which took place during the writer's period of office, under arrangements made in successive Programmes, involved an expenditure, from 1885 to 1902, of 88½ millions sterling, and the 245 ships of all classes, for which the writer was the responsible designer, had an aggregate value of about 80 millions sterling, exclusive of armaments and stores, or about 100 millions fully equipped. The capital value of the fleet in the same period was about trebled, and became 100 millions, exclusive of armaments. At the end of the French war (1813) the corresponding capital value was 10 millions; in 1860 it was under 18 millions; in 1878, 28 millions. The maintenance of supremacy at sea is a very costly undertaking in modern times, and the responsibility of the naval architect grows continuously.

Stability.

In regard to developments in the theory of naval architecture during the last ten years little need be said. The most marked change has been in the direction of wide extensions of scientific procedure in the designing of ships.

The scientific principles underlying calculations for the stability of ships, and the methods of calculation, have been long determined.

For more than a century the use made of these methods was very limited. Their practical application on a large scale received an enormous impetus from the inquiry which followed the loss of H. M. S. *Captain* in 1870. The chief advances made since that date have been the device and perfection of integrating machines, by which great economies of time and labour have been effected, and the accumulation of masses of experimental data for ships of various classes. Formerly, calculations for the stability of merchant ships were the exception. The introduction of novel types and the more general adoption of scientific procedure in design have, in recent years, led to widespread experimental investigation, and to detailed calculations for all classes of merchant ships. Indeed the practice for merchant ships is now very similar, in this respect, to that previously followed for warships.

One feature of great importance may be mentioned, which has been developed, during the last ten years, by the introduction, in battleships and armoured cruisers, of heavy guns with strong armour protection, placed high above water. Personally, the writer recognized the fact, from the first, that such a vertical distribution of weights must produce an unusually high position of the center of gravity, in proportion to the total depth of the ships; and that, even with high freeboard, there would be only moderate ranges in the curves of stability, as compared with preceding battleships and cruisers of high freeboard. For preceding high freeboard types, either for war or commerce, it had been usual and proper to assume that, if the metacentric height was sufficient, there would be ample range; but under the new conditions it seemed clear to the writer that this could no longer be true.

Calculations made (about 1893-94) for battleships of the *Majestic* class and for the cruisers *Powerful* and *Terrible* confirmed this anticipation, and showed that, notwithstanding the very high freeboard, the range of stability was only about 60°. At present one of the most critical questions to be faced by warship designers is that of securing adequate range of stability with heavy loads of armour and armament, which are required to be carried at great heights. In fact, so far as the character and range of curves of stability are concerned, the problems now arising are similar to

those which were dealt with, for vessels of moderate freeboard, by scientific members of the Committee on Designs for ships of war appointed by the British Admiralty in 1871. Their investigations for vessels of the "breastwork-monitor" type have consequently acquired fresh interest. Although these investigations were conducted on scientific lines, and secured the collaboration of men like Froude, Rankine, and Lord Kelvin, the solutions reached and the practical rules laid down were avowedly, and from the nature of the case could be, only approximate. To treat them as if they were exact and complete solutions, would be distinctly contrary to the views of the investigators themselves.

When guns of heavier calibers and greater lengths have to be mounted at considerable heights above water, in order to increase fighting efficiency, there is a temptation to accept limitations in range of stability, which may be of serious import in warships exposed to damage in action. Increase in breadth, of course, enables adequate metacentric heights and some addition to range, to be obtained, even under the conditions described. But everyone familiar with the subject is aware that while increase in beam, and consequent increase in metacentric height, produces some addition to range of stability, the gain is relatively small if the center of gravity is high in the ship. On the other hand the period of oscillation is rapidly diminished by increase in metacentric height, and quicker rolling is accompanied by loss of steadiness at sea, under critical conditions of wave motion. It is not overlooked that in modern types the greater area of armour protection and the greater vertical depth of armoured sides make ships much less liable to rapid diminution of their stability when exposed to gun fire in action; so that there is reason for accepting a less range of stability in the "intact" condition than with preceding ships of inferior protection. But the writer's conviction is that the question of range of stability, under existing conditions, does not always receive the attention it deserves; and that the tendency which now prevails to increase the caliber of guns in secondary armaments and to place them on upper decks, makes it most important to investigate the conditions of stability for each design thoroughly before accepting the desired armaments and protection.

As to merchant ships the cases requiring closest study are those incidental to cargo steamers, carrying great loads and very diverse cargoes. The designer has no control over the character or stowage of the cargoes. All that he can do is to assume certain conditions as being the worst likely to occur in practice, and to provide for them. Great attention is now given to such problems, and scientific procedure in regard to them is general. Legislation in regard to maximum load lines in British ships has greatly assisted designers in their work, by fixing one important feature. In essentials that legislation remains practically in the same form as it stood ten years ago.

Estimates of Speed and Engine Power.

In this section of ship design it cannot be said that the last ten years have added any important novelty in procedure; but there has been a large extension in the application of accepted methods based upon scientific investigation. The necessity for progressive steam trials and their thorough analysis is now generally recognized. Model experiments in specially constructed tanks are much more common, and are admitted to be essential to the complete study of designs for ships of unusual form or unprecedented speed. Leading shipbuilding firms are establishing their own experimental tanks; and a movement is now in progress for adding to these private establishments in England, a tank specially devoted to general research work on problems incidental to the movement of solid bodies through water and the efficiency of propellers. Experience to date establishes beyond question the opinion, long held by those most familiar with the subject, that, apart from experimental inquiry, mathematical investigation will never be capable of dealing conclusively with the causes influencing the efficiency of screw propellers, or the selection of the propellers best adapted to a particular ship. Fresh weight has been given to this argument by the introduction of rotary engines, with high speed of revolution, demanding propellers of unusual dimensions in relation to the power applied. All these matters are now receiving attention. They cannot but have a marked effect upon the economy and efficiency of future steamships both for war and for commerce. It is unnecessary to

reproduce many facts illustrating these general conclusions; a single example must suffice. The *Drake* class of armoured cruisers was designed for 23 knots speed on an eight hours' trial. The writer's estimate was that, if the choice of propellers was successful, the actual speed would be about 23½ knots. On the trial of the *Drake,* with the screws first fitted, 30 600 h. p. was developed and the corresponding speed was 23.05 knots. These screws had been selected on the basis of experiments with model screws made in the Admiralty tank. From progressive trials, however, it was ascertained that at the higher speeds the "slip" rapidly increased, and it was obvious that greater blade area was required. New blades were made of the same diameter, rather less pitch, and about 38% greater area. With 31 400 h. p. the speed attained with these propellers was 24.11 knots, corresponding to 24 knots for 30 600 h. p., and 23.05 knots for 26 000 h. p. That is to say, the change of propeller blades produced an economy in power of 15% at 23 knots, and enabled a knot greater speed to be realized at full power. Equally striking examples might be given from experience with other classes, and particularly with destroyers, all of them indicating the necessity for further experiments on a large scale to supplement model experiments with screws and to furnish a proper scale of comparison.

One of the latest and most striking examples of the value of tank experiments has been furnished in connection with the design of the great Cunard steamships now building, which are to be capable of maintaining an average speed of 24½ knots across the Atlantic in fair weather. Here, in association with the selection of the most suitable dimensions and form, and the settlement of novel problems arising from the use of four shafts and propellers driven by steam turbines, it would have been impossible to proceed with confidence apart from tank experiments on models. By the courtesy of the Admiralty these experiments have been exhaustively completed with the greatest advantage to the owners and designers of the ships.

In conclusion it is necessary to repeat the statement that within the limits of this paper anything like a comprehensive survey of the progress of British Shipbuilding since 1894 is impossible. As one who has been in close touch with fellow workers in all departments,

and who has himself been actively engaged, it has been the writer's endeavour to note the chief features in a remarkable period, and to indicate present tendencies. He trusts that the review, imperfect as it is acknowledged to be, will have some interest for the members of this Congress.

TRANSACTIONS

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NAVAL ARCHITECTURE.

THE DEVELOPMENT OF JAPANESE SHIPBUILDING.

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Early History.—The shipbuilding industry in Japan may be said to have originated in prehistoric ages, and the importance of encouraging shipbuilding in this Island Empire had been felt as early as nearly 2 000 years ago, the first Imperial edict in relation thereto having been issued in 80 B. C. by the tenth Emperor, "Sujin-Tenno." Most of the ships in those days were undoubtedly of canoe-build, cut from solid blocks of timber, but their form and construction underwent gradual improvement, and they were increased in number and size. It seems quite certain that many of them were engaged in ocean navigation since the latter part of the first century between the home and Corean ports; it is also recorded that as far back as 200 A. D. a large fleet under the command of the Empress "Jingo" invaded Corea. At the end of the third century, Corean methods of ship construction were introduced, causing a radical change in Japanese shipbuilding, and more seaworthy ships began to be constructed. Communication with the coast of China was established in the early part of the fourth

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century, and her modes of shipbuilding were also gradually introduced during the seventh century. Another epoch in the history of Japanese shipping was thus formed, and Japanese ships underwent changes in their construction, becoming a mixture of native, Corean and Chinese systems. The junks had been gradually increased in size, and those greater than 100 ft. in length were not uncommon in the eighth century. Marked differences between war and merchant ships, however, do not seem to have existed in those days.

Japanese ocean shipping was once interrupted in the tenth century, a natural check was given to the growth of shipbuilding. and ships were built only for pleasure purposes. But after the invasion of the Mongolian fleet in 1274 and 1281, in which Japan won glorious victories and the whole Mongolian fleet was destroyed or sunk, the shipping and shipbuilding trades again began to assume great activity. From this period, ships underwent different stages of improvement, mostly Chinese in idea, becoming gradually larger and more seaworthy. Ocean trade was greatly developed during the middle of the sixteenth century. Restricted to China and Corea in the older days, the foreign trade was gradually extended to Europe and Australasia, and, in the early part of the seventeenth century, the Shogun's government (of the Tokugawa Dynasty) began to give special licenses to ships trading to these countries. In 1617 there were 198 vessels with licenses for ocean trade, including Annam, the Philippines, Siam, Cochin-China and other places. These licensed ships were the best sea boats at that period, from 90 to 120 ft. in length, mostly constructed after the Chinese or western style. Such is a general statement of the growth of Japanese junk building up to the early years of the seventeenth century.

First Ships of Western Type.—Ships of western style began to be built in Japan early in the seventeenth century, by the first Shogun, Iyeyasu, of the Tokugawa family, under the supervision of William Adams, who was an English pilot, the survivor from a Dutch ship. Though imprisoned for a time, Adams eventually gained his liberty and settled in Japan in 1599. Two ships, one of 80 and the other of 120 tons, were the first built under the direction of this interesting intruder. In one of these ships some

Spaniards who had been wrecked on the east coast of Japan were sent to Acapulco in 1610.

Law Limiting the Size of Ships.—It is to be regretted that, at about that time, being alarmed at the progress of Christianity, a strict law limiting the size of ships was passed, which was followed by laws prohibiting foreign trade; and in 1639 communication with other countries was entirely stopped; no foreign ships, except those of China, Corea and Holland, were allowed to enter Japanese ports under any pretence whatever. This completely checked the progress of Japanese shipbuilding for the second time, and for nearly 220 years, small and not very seaworthy ships were built for the coasting trade only. During this period Japanese shipping remained quite in obscurity.

After the treaty with the United States was signed, in 1853, the necessity for developing the war and merchant navies was strongly felt, and the laws prohibiting foreign trade and limiting the size of ships were abolished at once, and ships of western type again began to be built; but, owing to the absence of intercourse with the western civilized nations for nearly two centuries, Japanese shipbuilders were quite destitute of sufficient technical knowledge, and ships constructed according to the so-called "western type" only resembled them in their outward appearance, being in reality nothing but reproductions of old-fashioned junks.

Forerunner of the Present Shipbuilding.—The beginning of the Japanese shipbuilding industry of to-day was obtained from the Russians. A Russian war vessel, the *Diana,* lying at anchor at the Port of Shimoda, and demanding a treaty with Japan, was washed ashore and sunk by tidal waves following the great earthquake of November 4th, 1854. Captain Putiatin, commanding the expedition, having decided to build new ships to take his men home, selected a place on Heda Bay, in the Province of Kimisawa, in Idzu, not very far from Shimoda, and started the construction of two wooden schooners with timber grown in that district. He employed many Japanese ship carpenters to assist his crew in the building of these ships. Thus they became acquainted with the construction of ships of the western type, and, after the completion of the Russian schooners, they built many of similar type, in different places throughout Japan. These vessels were known for some time as the

"Kimisawa type," after the place where the first schooners were built. Proper methods of western shipbuilding were thus introduced and spread over Japan. They have had a rapid and striking development in the last forty years.

First Warship.—In 1855 a war vessel was presented to the Shogun by the Dutch Government, being the first war steamer afloat in Japanese waters. In 1857 another war vessel, fitted with a screw propeller, was purchased from the Dutch Navy, and was followed by a few more. These, with a steam yacht presented to the Shogun by the late Queen Victoria in 1858, formed the nucleus of the present Japanese Navy. Warships were also bought by the heads of the different clans.

First Shipyard.—The Government of the Shogun, being supplied with naval vessels, had formed an idea of having shipyards for building and repairing these vessels. The first shipyard in Japan was started in Akunoura, in Nagasaki Harbour, in 1857. Dutch engineers and shipwrights were employed, and necessary machinery and gear for commencing the works were imported from Holland. Many apprentices were sent to Nagasaki by the Shogun's Government and also from different clans, to learn ship and engine construction. In consequence, it is noticeable that Dutch terms are still often used by old hands in many shipyards and engine works, all over Japan.

Engine works were started in Yokohama in 1865, and also in Yokosuka in the same year. The latter had been planned by a French engineer, M. Verny, and it took nearly four years to construct a dry dock and fit out the dockyard. When completed, the whole establishment had to be handed over to the present Government, owing to the final overthrow of the Shogunate in 1868.

Permission for Merchant Ship Owning.—In 1861 permission was given to the general public to own large vessels of western construction. Many ships, both sailing and steam, were built and bought, and at the time of the restoration of the Emperor to power, in 1868, there were forty-six merchant vessels of western type, having an aggregate tonnage of 17 000 tons.

First War Vessel Built in Japan.—The first screw war vessel, the *Chiyodagata*, was built at Ishikawajima, a small island at the mouth of the River Sumida in Tokio, in 1866, by men educated at the

Nagasaki Engine Works; she was the first ship built solely by Japanese hands.

Japanese Navy and Warship Building.—After the Restoration, in 1867, the Japanese Navy was organised, mainly with ships confiscated from the Shogun and the other Daimyos (heads of the different clans); it embraced nine or ten ships, ranging in displacement from 200 to 1 000 tons, mostly wooden gunboats or sloops-of-war. The Government then commenced to develop the navy by building new ships, abroad as well as at home.

The first warship built in Yokosuka after the dockyard there had passed into the hands of the Imperial Government, was the *Seiki*, a wooden gunboat of 900 tons displacement, launched in 1876; this was followed successively by the *Amagi, Banjo, Kaimon, Tenriu,* etc., of somewhat similar type. The central-battery ironclad *Fuso,* and the armoured composite corvettes *Kongo* and *Hiyei,* were the first ships ordered from England, and were all launched in 1877. The composite sloops, *Katsuragi* and *Musashi,* of 1 476 tons displacement, still on the active list, were launched inYokosuka in 1885 and 1886, being the first and last of this type built in Japan; the *Yamato,* a sister ship, had been ordered from Mr. Kirby's yard in Kobe, and was the first warship built under contract in Japan. The *Takao,* a small cruiser of 1 750 tons, designed in 1886 and launched in 1888, was the first iron warship built in Japan.

At about the same time, three iron gunboats of 615 tons were built, the *Atago* in Yokosuka, the *Maya* in Kobe, and the *Chokai* in Ishikawajima (a private yard). These, with the *Akagi,* the first steel gunboat, of the same displacement as the *Ataga* class, launched in 1888, formed an epoch in the history of Japanese warship building. The principal vessels constructed in Yokosuka, before the late war with China, were the *Yayeyama,* a despatch vessel of 1 600 tons displacement and 20 knots speed, launched in 1889, the fastest ship in the Japanese Navy at that time; the *Akitsushima,* a protected cruiser of 3 100 tons and 19 knots, launched in 1892; and the *Hashidate,* a cruiser of 4 300 tons, launched in 1891, the latter forming a triplet with the *Itsukushima* and *Matsushima,* built in France, and then the most powerful ships in the navy.

The Naval dockyards at Kure and Sasebo were newly opened a few years before the war of 1894, and equipped with shipbuilding

and repairing facilities, but no work of importance was turned out before the war.

The Japanese Navy, at the time of the war, consisted of four armoured ships of small and inferior classes, seven second-class cruisers, fifteen small cruisers and gunboats, and two torpedo-boats, aggregating about 55 000 tons in displacement, of which fourteen ships were home built.

Japanese Navy after the Chinese War.—After the war with China, Japan took active steps to embark on an enormous naval extension programme, with a total expenditure of about £22 000 000 sterling, extending over ten years. The ships built under this programme, with those already building or contracted for at the time of the war, include:

- 6 First-class battle-ships: 4 of the *Shikishima* type, 15 000 tons and 18 knots, and 2 of the *Fuji* type, 12 500 tons and 18 knots;
- 6 Armoured cruisers, of the *Asama* type, 10 000 tons and from 20 to 23 knots;
- 3 Second-class cruisers, of the *Chitose* type, 4 500 tons and 23 knots;
- 5 Third-class cruisers: 2 of the *Tsushima* type, 3 400 tons and 20 knots, the *Otowa,* 3 000 tons and 21 knots, and 2 of the *Akashi* type, 2 700 tons and 20 knots;
- 2 Despatch vessels; the *Miyako,* of 1 800 tons, and the *Chihaya,* of 1 250 tons;
- 3 Shallow-draft gunboats;
- 20 Torpedo-boat destroyers;
- 63 Torpedo-boats of various sizes.

Of these 108 vessels, totaling about 180 000 tons in displacement, added in the last ten years, only a few were built in the Naval dockyards, *viz.,* those given in Table 4.

Torpedo boats, 63 in all, were built in Yokosuka, Kure, Sasebo and other yards.

Naval Works.—In connection with the programme, very large extensions have also been carried out in the naval dockyards at Yokosuka, Kure and Sasebo, by building graving docks, erecting new shops, and by adding machinery of the most modern description.

A new dockyard has also been started in Maizuru, and small repairing works in other minor naval ports. The Japanese Navy thus possesses all the necessary equipment and facilities for building warships of any description whatever.

TABLE 4.

Name.	Displacement.	Dimensions.	Speed, in knots.	Date of launch.	Where built.
Niitaka	3 400	334¾ x 44 x 16¼	20	1902	Yokosuka.
Otowa	3 000	321⅓ x 41¼ x 15¾	21	1903	"
Suma	2 700	306 x 40 x 15¼	20	1895	"
Akashi	2 800	295 x 41¾ x 15¾	19½	1896	"
Chihaya	1 250	275 x 31½ x 9	21	1900	"
Harusame, *Hayatori*, *Murasame*, *Asagiri*	375	227 x 21½ x 6	29	1902	"
Tsushima	3 400	334¾ x 44 x 16¼	20	1903	Kure.
*Miyako**	1 800	315 x 34½ x 14	20	1897	"
Uji	620	180 x 27½ x 6-10½	13	1903	"

* The *Miyako* was sunk at Talien Bay, in May. 1904.

Future Extensions.—The step taken by the Japanese Navy was immediately followed by the expansion of the naval fleets of all other important maritime nations, and it was soon found necessary to reinforce the navy again, in order to keep up the position once attained in the world's navy list. With this object in view, another naval programme, involving the total expenditure of £10 000 000 sterling, extending over ten years, was voted in the Diet in the session of 1903-04, and, among other developments, an armour-plate rolling plant will be laid down in Kure Arsenal.

Early Merchant-Ship Building.—Of the shipyards started by the Shogun and some of the Daimyos, those at Yokosuka, Yokohama and Ishikawajima were transferred to the Navy Department at the Restoration, while the yard at Nagasaki passed to the Industrial Department, under whose superintendence merchant-ship building was commenced. A new shipyard in Kobe was also started shortly afterward, by the last-named department. Again, in 1876, the site of the Ishikawajima Engine Works was leased to a private individual, Mr. T. Hirano, a native of Nagasaki, who was trained at the Nagasaki works. He soon started shipbuilding and engine works under the name of the Hirano Shipyard which was after-

ward renamed "The Ishikawajima Shipbuilding and Engineering Company." This was really the first private yard of the modern type founded in Japan. There were, besides, a few yards converted from those building ships of the native type, and also a few started by foreigners in Kobe and other places. Provided with these facilities, ships of western type began to be constructed, and gradually increased in number; they were mostly of wooden build, and of very small dimensions, suitable for coasting trade only. In those days, steamers were quite new to the general shipowners and sailors; the superiority of sailing ships of western type over the ordinary Japanese junks being only too evident, most of the vessels built in the early years were sailers. From 1870 to 1885, 266 steamers (of more than 20 tons) of 16 582 gross tons, and 531 sailing ships (of more than 20 tons) of 49 666 tons were built in Japan, the sailing ships being twice the number and three times the tonnage of the steamers.

The *Kosuge Maru,* of 1 500 gross tons, built in Nagasaki in 1883, at the order of the Union Transport Company (which was amalgamated with the Nippon Yusen Kaisha in 1885), was the only vessel of more than 1 000 tons built in Japan before the war of 1894. The first iron merchant ship was the *Denshin Maru,* of 260 tons, built at Tokio in 1873, which was followed later by many others.

Although the shipbuilding industry was making progress, it was so insignificant that, of 84 steamers of more than 1 000 gross tons, existing at the end of 1894, only one, the *Kosuge Maru,* was built in Japan, and even of some 70 vessels, of between 500 and 1 000 gross tons, only about one-half were home built.

Number of Japanese Merchant Ships Before the War of 1894-95. —The number of merchant ships owned in Japan, just after the Restoration, was 46, having a total tonnage of 17 000. At the end of 1893, just prior to the war with China, these figures had increased to 1 429 vessels (of which 400 steamers and 218 sailing ships were of more than 20 tons), aggregating 225 000 gross tons, an increase of nearly thirty times in numbers and thirteen times in tonnage, in more than twenty years; this shows the slow but steady progress of Japanese shipping made in earlier days. Of the total imports and exports during that period, nearly one-tenth by tonnage, or one-thirteenth by value, was carried under the Japanese flag.

The late war with China really marks a point in Japanese history from which dates the sudden expansion in its commerce, industry and every branch of business, but nothing is so striking as the sea progress made in the last ten years.

Shipping and Shipbuilding Subsidies.—During the Chinese war, there was a great demand for transports, and a large number of Japanese merchant ships were chartered and used for this service.

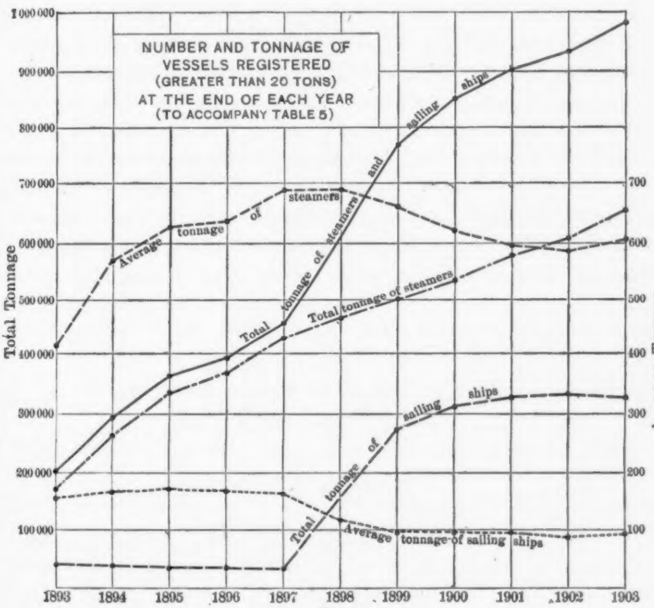

FIG. 1.

In consequence, the shipping trade was actually stopped. To meet the urgent necessity, 38 steamers, all second-hand, aggregating 96 000 tons, were purchased in 1894. After the war, the importance of expanding Japanese shipping and shipbuilding having been perceived, in regard both to military and commercial requirements, the Government resolved to encourage them by giving subsidies, and, in 1896, acts were passed, to remain in force for eighteen years.

Under these acts, an amount is paid at the rate of 25 sen (about 12½ cents) per gross ton per 1 000 miles, for Japanese steamers, of 1 000 gross tons and 10 knots speed, engaged in foreign trade. The rate of subsidy is increased according to the size and speed, 60 sen (about 30 cents) being the highest rate, for ships of 6 000 tons and 17 knots speed. The subsidy, however, varies with the age of the steamers, the full amount being paid for the first five years from the date of launching, reduced 5% every year after the fifth year, and altogether withdrawn at the fifteenth year.* The encouragement thus given being found to be still insufficient for those entering into competition with well-established foreign steamship companies, subsidies under special contracts are paid to those making regular service on certain definite routes, among which may be counted the European line, Australian line, Bombay line, American line, etc. Table 5 shows the growth of the Japanese mercantile marine in the last ten years. The total tonnage has increased nearly five times during this period. Japan's foreign trade has also increased more than three times in the same period, and ships entering and clearing Japanese ports in 1902 totaled 23 000 000 tons, of which nearly 37% was under the Japanese flag.

TABLE 5.—NUMBER AND TONNAGE OF VESSELS REGISTERED (ABOVE 20 TONS) AT THE END OF EACH YEAR.

Year.	Steamers.		Sailing Ships.		Total.	
	Number.	Gross tonnage.	Number.	Gross tonnage.	Number.	Gross tonnage.
1893	400	167 490	218	33 666	618	201 156
1894	461	331 374	196	32 103	657	295 732
1895	528	331 374	173	29 322	711	360 696
1896	570	363 223	165	27 111	735	390 334
1897	626	426 624	171	27 412	797	454 036
1898	674	464 246	1 310	149 385	1 984	613 631
1899	753	498 376	2 783	270 162	3 536	768 538
1900	859	534 239	3 309	306 393	4 168	840 632
1901	969	577 195	3 565	324 995	4 534	902 190
1902	1 033	605 122	3 951	329 839	4 624	934 961
1903	1 088	657 269	3 514	322 154	4 602	979 423

The sudden increase in the number and tonnage of sailing ships in 1898 is due to the inclusion of "half-caste" sailing vessels in the register since that time. Half-caste boats are really junks, but with some approach to the Western type, in the matter of frames, planking and rigging, to obtain something more seaworthy than the junk had proved itself to be.

* This rate of subsidy refers only to home-built ships, half the amount being paid to those built abroad.

Under the Shipbuilding Subsidy Act, 20 yen (about $10 in gold) per ton are paid on iron or steel vessels, of more than 1 000 gross tons, built in Japan, and 12 yen (about $6) on ships of between 700 and 1 000 gross tons, and an additional sum is paid on machinery, at the rate of 5 yen (about $2.50) per indicated horse power actually developed on the official trial. All subsidised vessels are required

NUMBER AND TONNAGE OF VESSELS
(GREATER THAN 20 TONS)
ADDED TO THE REGISTER EACH YEAR
(TO ACCOMPANY TABLE 7)

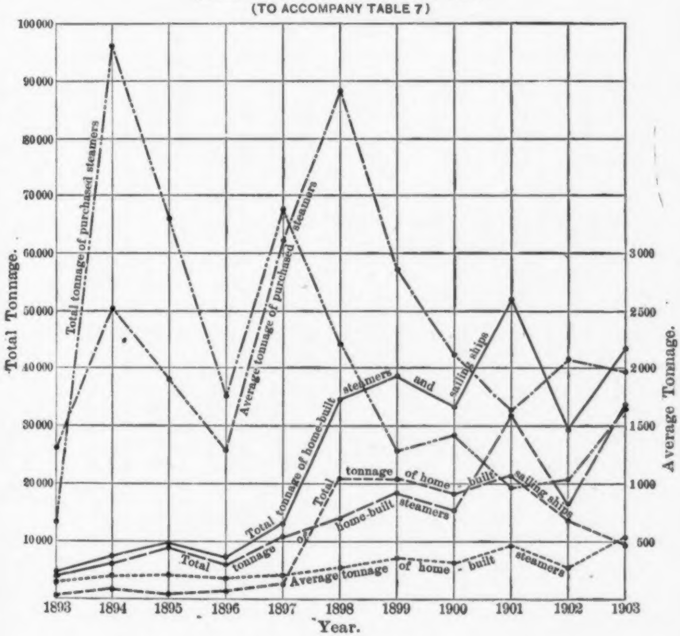

FIG. 2.

to be built according to the shipbuilding regulations, published by the Japanese Marine Bureau, which are somewhat similar to the British Lloyd's rules. There were 43 ships built or building in Japan at the end of 1903, to take advantage of this act; the total tonnage is 100 900, the total indicated horse power is 83 350, and their general particulars are shown in Table 6.

Kōtsū-Maru	Spar deck.	Ishikawajima.	Ōya.	240 ft. 0 in. x 34 ft. 0 in. x 15.45 ft.	1 600	12.23	1 367
Ta-Chi-Maru........	Twin screw, shallow draft.	Osaka Iron Works.	O. S. K.	250 ft. 0 in. x 40 ft. 0 in. x 10 ft. 3 in.	2 076	10.89	1 487
Oura-Maru	Flush deck.	Mitsu Bishi.	Mitsu Bishi.	184 ft. x 29 ft. x 16.92 ft.	713	12.29	690
Wakamatsu-Maru ...	Three-deck.	"	"	318.2 ft. x 42 ft. x 26 ft.	2 774	12.39	2 279
Daiya-Maru..........	"	"	"	318.2 ft. x 42 ft. x 26 ft.	2 795	13.24	2 365
Riushin.............	Twin screw, flush deck.	Kawasaki.	Chinese Custom.	185 ft. 0 in. x 28 ft. 6 in. x 16 ft. 7 in.	724	12.57	1 319
Kei-Jō-Maru	Two-deck.	"	O. S. K.	210 ft. x 31.6 ft. x 20 ft.	1 208	12.19	1 312
Aki-Maru...........	Twin screw, three-deck.	Mitsu Bishi.	N. Y. K.	443 ft. 0 in. x 49 ft. 2 in. x 34 ft. 6¼ in.	6 444	15.36	5 448
Kushiro-Maru	Awning deck.	Kawasaki.	"	218.9 ft. x 29 ft. x 16.1 ft.	1 076	12.96	1 344
Che-Foo-Maru........	Spar deck.	Mitsu Bishi.	"	254 ft. 7 in. x 36 ft. 6 in. x 17 ft. 2 in.	1 934	12.4	1 565
Heijo-Maru...........	"	Kawasaki.	O. S. K.	210.8 ft. x 31.6 ft. x 20.0 ft.	1 204	11.97	1 186
Niigata-Maru........	Three-deck.	Mitsu Bishi.	N. Y. K.	277 ft. 4 in. x 39 ft. 6 in. x 24 ft. ⅞ in.	2 184	12.3	1 577
Yeiko-Maru	Spar deck.	"	"	254.7 ft. x 36.6 ft. x 17.2 ft.	1 966	12.88	1 963
Shen-Kiang.........	Twin screw, shallow draft.	Osaka Iron Works.	Hu-nan S. S. Co.	193 ft. 11 in. x 38 ft. 0 in. x 7 ft. 9⅛ in.	935	10.66	815
Yuen-Kiang.	"	"	"	193 ft. 11 in. x 38 ft. 0 in. x 7 ft. 9½ in.	935	10.4	750
Kōriō-Maru..........	Spar deck.	"	Fujino.	178.88 ft. x 77 ft. x 12.56 ft.	745.6	10.58	524
Nikkō-Maru..........	Three-deck.	Mitsu Bishi.	N. Y. K.	418 ft. 2 in. x 50 ft. 0 in. x 31 ft. 6½ in.	5 539	17.76	6 780
Ceylon-Maru	"	"	"	383 ft. 2 in. x 48 ft. 6 in. x 30 ft. 9 in.	5 068	14.1	3 832
Taisei-Maru........	Two-deck sailing ship.	Kawasaki.	Nautical College.	268.3 ft. x 44 ft. x 27.67 ft.	2 287	9.98	932
Dai Tei-Maru........	Spar deck.	Mitsu Bishi.	O. S. K.	210 ft. 9¾ in. x 31 ft. 6 in. x 14 ft. 8 in.	1 197	12.75	1 378

TABLE 6.—GENERAL PARTICULARS OF SHIPS BUILT IN JAPAN UNDER SHIPBUILDING SUBSIDY ACT.

Name.	Type.	Builder.	Owner.	Principal Dimensions.	Gross tonnage.	Trial Results. Speed.	Trial Results. Indicated horse power.
Kitami-Maru	Awning deck.	Kawasaki.	N. Y. K.	180 ft. 0 in. x 26 ft. 6 in. x 13 ft. 5 in.	728	11.1	877
Tsukishima-Maru ...	Two-deck sailing ship.	Mitsu Bishi.	Nautical College.	238 ft. 2 in. x 38 ft. 6 in. x 24 ft. 3 in.	1 519	8.6	306
Hitachi-Maru	Twin screw, three-deck.	"	N. Y. K.	443 ft. 0 in. x 49 ft. 2 in. x 34 ft. 6 in.	6 172	14.28	3 889
Ta-Yuen-Maru	Twin screw, shallow draft.	Kawasaki.	O. S. K.	230 ft. 0 in. x 40 ft. 0 in. x 10 ft. 0 in.	1 695	10.50	1 042
Awa-Maru	Twin screw, three-deck.	Mitsu Bishi.	N. Y. K.	443 ft. 0 in. x 49 ft. 2 in. x 34 ft. 6 in.	6 309	14.03	4 112
Akunoura-Maru	Two-deck.	"	Mitsu Bishi.	260 ft. 0 in. x 37 ft. 0 in. x 19 ft. 0 in.	1 717	11.55	1 340
Ta-Han-Maru	Twin screw, shallow draft.	"	O. S. K.	270 ft. 0 in. x 40 ft. 0 in. x 12 ft. 6 in.	2 243	13.18	2 242
Ta-Lee-Maru	"	Kawasaki.	"	270 ft. 0 in. x 40 ft. 0 in. x 12 ft. 6 in.	2 246	12.48	2 210
Dai-Jin-Maru	Spar deck	"	"	243.7 ft. x 33.9 ft. x 15.7 ft. (M. Dk.)	1 576	12.6	1 875
Dai-Gi-Maru	"	Osaka Iron Works.	"	250 ft. 0 in. x 34 ft. 0 in. x 22 ft. 0 in.	1 568	12.48	1 914
Kaga-Maru	Twin screw, three-deck.	Mitsu Bishi.	N. Y. K.	443 ft. 0 in. x 49 ft. 2 in. x 34 ft. 6 in.	6 301	15.15	5 410
Hidaka-Maru	Awning deck.	Kawasaki.	"	179.9 ft. x 26.84 ft. x 14.22 ft.	735	11.34	690
Tokachi-Maru	"	"	"	218.7 ft. x 29 ft. x 16.1 ft.	1 110	13.15	1 285
Ta-Chang-Maru	Twin screw, shallow draft.	Mitsu Bishi.	O. S. K.	270 ft. 0 in. x 40 ft. 0 in. x 13 ft. 0 in.	2 712	12.9	690
Iyo-Maru	Twin screw, three-deck.	"	N. Y. K.	443 ft. 0 in. x 49 ft. 2 in. x 34 ft. 6 in.	6 320	15.37	5 106
Teshio-Maru	Awning deck.	Kawasaki.	"	218.7 ft. x 29 ft. x 16.1 ft.	1 107	12.84	1 730

Ta-Chi-Maru.........	2	"	13 x 21½ x 35¼ / 24	2	14 ft. 3 in. x 10 ft. 6 in.	September, 1901.
Oura-Maru.....	1	"	13 x 22 x 36 / 27	1	13 ft. 3 in. x 9 ft. 7 in.	December, 1901.
Wakamatsu-Maru....	1	Quadruple.	28½ x 29 x 42 x 60 / 45	1	15 ft. 6 in. x 17 ft. 8½ in.	February, 1902.
Daiya-Maru..........	1	"	28½ x 29 x 42 x 60 / 45	1	15 ft. 6 in. x 17 ft. 8½ in.	April, 1902.
Riushin...............	1	Triple.	13½ x 22 x 36 / 22	2	10 ft. 6 in. x 13 ft. 0 in.	June, 1902.
Kei-Jō-Maru..........	1	"	18 x 29 x 50 / 33	2	12 ft. 9 in. x 10 ft. 0 in.	September, 1902.
Aki-Maru	2	"	20 x 33½ x 56 / 48	2 2	13 ft. 9 in. x 16 ft. 5½ in. 13 ft. 10⅜ in. x 9 ft. 5½ in.	October, 1902.
Kushiro-Maru	1	"	17½ x 28 x 46 / 33	2	11 ft. 0 in. x 11 ft. 0 in.	December, 1902.
Che-Foo-Maru........	1	"	21 x 35 x 58 / 36	1 2	9 ft. 0 in. x 9 ft. 1 in. 13 ft. 9 in. x 9 ft. 11½ in.	" 1902.
Heijo-Maru...........	1	"	17½ x 28 x 46 / 33	2	12 ft. 3 in. x 10 ft. 3 in.	January, 1903.
Niigata-Maru........	1	"	21 x 35 x 58 / 36	2	12 ft. 0 in. x 10 ft. 9 in.	May, 1903.
Yeiko-Maru...........	1	"	21 x 35 x 58 / 36	2	12 ft. 9 in. x 11 ft. 0 in.	June, 1903.
Shen-Kiang...........	2	"	10 x 16 x 28 / 15	1	13 ft. 9 in. x 10 ft. 6 in.	July, 1903.
Yuen-Kiang...........	2	"	10 x 16 x 28 / 15	1	13 ft. 9 in. x 10 ft. 6 in	August, 1903.
Kōriō-Maru...........	1	"	13 x 21½ x 37 / 27	1	12 ft. 0 in. x 10 ft. 0 in.	September, 1903.
Nikkō-Maru	1	"	31 x 51 x 85 / 54	2	15 ft. 6 in. x 17 ft. 5 in. 15 ft. 7½ in. x 9 ft. 10¾ in.	" 1903.
Ceylon-Maru	1	"	26½ x 43 x 72 / 48	3	13 ft. 4½ in. x 10 ft. 11 in.	December, 1903.
Taisei-Maru..........	2	"	13 x 21 x 33 / 27	2	12 ft. 0 in. x 10 ft. 3 in.	1904.
Dai-Tei-Maru	1	"	17 x 28 x 46 / 33	1	15 ft. 1 7/16 in. x 10 ft. 8 3/16 in.	1904.

Ships under construction at the end of June, 1904: *Tango-Maru*, 7 300 tons and 5 500 h. p.; *Chohakusan-Maru*, 2 000 tons and 1 400 h. p.; at Mitsu Bishi Dockyard Company, Nagasaki; A Corean light-house tender, 1 100 gross tons and 1 800 h. p.; *Kunsan* and *Mokupo*, 775 tons and 800 h. p. each, at the Kawasaki Dockyard Company, Limited, Kobe; *Anto-Maru* and *Gishū-Maru*, 776 tons and 700 h. p., at the Osaka Iron Works, Osaka.

TABLE 6.—(*Continued.*)

Name.	Engines.			Boilers.		Date of completion.	Remarks.
	Number.	Type.	Size of cylinders.	Number.	Size.		
Kitami-Maru	1	Triple.	16 x 26½ x 43 / 30	....	....	October, 1897.	
Tsukishima-Maru	1	"	13 x 21 x 34 / 27	1	10 ft. 0 in. x 10 ft. 6 in.	March, 1898.	Lost in November, 1901.
Hitachi-Maru	2	"	20 x 33½ x 56 / 48	2 2	13 ft. 3 in. x 17 ft. 0 in. 13 ft. 3 in. x 10 ft. 0 in.	April, 1898.	Attacked and sunk by Russian fleet in June, 1904.
Ta-Yuen-Maru	2	"	12⅛ x 21 x 34 / 21	....	....	February, 1899.	
Awa-Maru	2	"	20 x 33⅛ x 56 / 48	2 2	13 ft. 3 in. x 17 ft. 0 in. 13 ft. 3 in. x 10 ft. 0 in.	July, 1899.	
Akunoura-Maru	1	"	18½ x 30 x 44½ / 36	2	13 ft. 0 in. x 10 ft. 6 in.	November, 1899.	Lost in August, 1904.
Ta-Han-Maru	2	"	16 x 25 x 43 / 30	2	12 ft. 0 in. x 15 ft. 6 in.	June, 1900.	Lost by fire, January, 1904.
Ta-Lee-Maru	2	"	16 x 25 x 43 / 30	2	12 ft. 0 in. x 15 ft. 6 in.	" 1900.	
Dai-Jin-Maru	1	"	22 x 36 x 59 / 36	2	12 ft. 6 in. x 16 ft. 0 in.	September, 1900.	
Dai-Gi-Maru	1	"	22 x 36 x 59 / 36	2	12 ft. 6 in. x 16 ft. 0 in.	December, 1900.	
Kaga-Maru	2	"	20 x 33½ x 56 / 48	2 2	13 ft. 9 in. x 16 ft. 5 in. 13 ft. 9 in. x 9 ft. 5⅛ in.	June, 1901.	
Hidaka-Maru	1	"	16 x 26 x 43 / 30	1	14 ft. 0 in. x 10 ft. 6 in.	May, 1901.	
Tokachi-Maru	1	"	17⅛ x 28 x 46 / 33	2	12 ft. 6 in. x 10 ft. 0 in.	June, 1901.	
Ta-Chang-Maru	1	"	16 x 26 x 43 / 30	1	14 ft. 0 in. x 10 ft. 6 in.	August, 1901.	
Iyo-Maru	2	"	20 x 33½ x 56 / 48	2 2	13 ft. 9 in. x 16 ft. 5 in. 13 ft. 9 in. x 9 ft. 5½ in.	" 1901.	
Teshio-Maru	1	"	17⅛ x 28 x 56 / 33	2	12 ft. 6 in. x 10 ft. 0 in.	" 1901.	
Kōtsū-Maru	1	"	18½ x 30⅛ x 52⅛ / 36	2	12 ft. 6 in. x 11 ft. 1 in.	" 1901.	

Table 7 shows the number of vessels added to the register each year, by the new building at home, and also by purchase from abroad; the rapid growth of the shipbuilding industry is indicated clearly by this table. Table 7 also shows the number of shipyards existing at the end of each year. Of these, the majority are of very small size, and only capable of building wooden sailing ships and junks. The distribution of shipyards along the coast line of the Empire can be seen from the map, Fig. 3.

TABLE 7.—NUMBER AND TONNAGE OF VESSELS (ABOVE 20 TONS) ADDED TO THE REGISTER EACH YEAR.

Year.	Number of Shipyards.	Built at Home.				Purchased from Abroad.			
		Steamers.		Sailing Ships.		Steamers.		Sailing Ships.	
		Number.	Gross. tonnage.	Number.	Gross tonnage.	Number.	Gross tonnage.	Number.	Gross tonnage.
1893...	58	26	3 967	4	459	10	.13 036	2	1 778
1894...	53	33	5 847	10	1 311	38	96 072	......	....
1895...	57	47	8 977	6	951	35	66 424	......	....
1896...	66	36	5 860	11	1 061	27	34 891	......	....
1897...	81	57	10 696	18	2 472	22	67 454	......	....
1898...	106	54	13 929	202	20 836	10	44 110	......	....
1899...	148	53	18 157	216	20 342	9	25 474	1	83
1900...	153	53	15 308	193	17 873	13	28 492	2	235
1901...	169	71	31 829	202	20 255	12	19 344	1	113
1902...	186	67	16 328	137	13 035	10	20 684	......	....
1903...	185	65	33 612	124	9 925	17	33 440	1	161

The sudden increase in the number and tonnage of sailing ships in 1898 is due to the inclusion of "half-caste" sailing ships in the Register since that time. "Half-caste" boats are really native junks, but with some approach to Western type, in the matter of framing, planking and rigging, in order to obtain something more seaworthy than junks had proved themselves to be.

Such is a general statement of the development of navy and merchant shipbuilding in Japan, and before the writer ventures to give a few comparisons of the efficiency of ship construction during the last ten years, it may be of some interest to trace very roughly the growth of the principal shipyards. Detailed descriptions of the naval dockyards are not permissible, and notes of the private yards, only, are given.

The Mitsu Bishi Dockyard.—The Mitsu Bishi Dockyard and Engine Works (Plate I) at Nagasaki, the largest and oldest shipbuilding establishment in Japan, consist of the engine works at Akunoura,

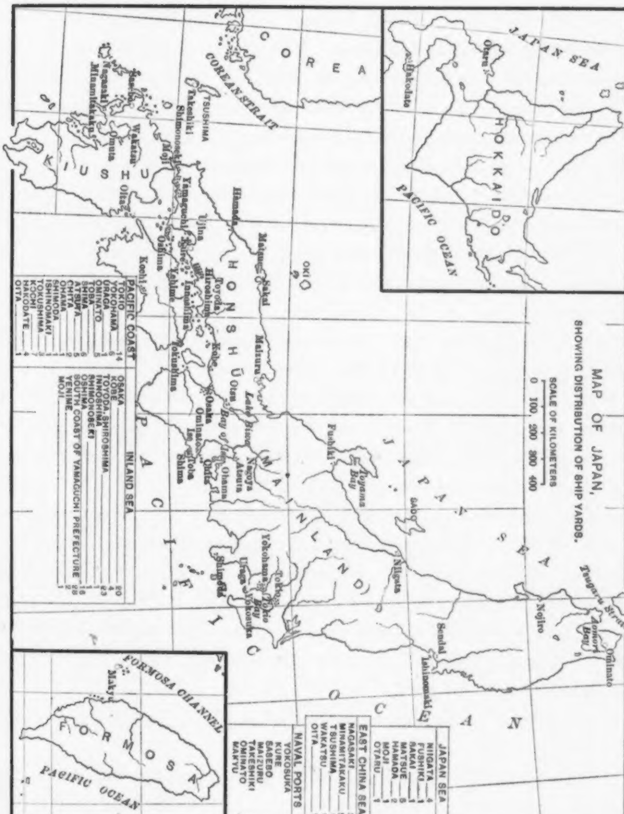
MAP OF JAPAN,
SHOWING DISTRIBUTION OF SHIP YARDS.
SCALE OF KILOMETERS
0 100 200 300 400
JAPAN SEA
PACIFIC OCEAN
HOKKAIDO
COREA
COREAN STRAIT
KIUSHU
HONSHU
MAINLAND
FORMOSA CHANNEL
FORMOSA
PACIFIC COAST
INLAND SEA
EAST CHINA SEA
NAVAL PORTS

FIG. 3.

the shipyard and dry docks at Tategami, and the patent slip at Kosuge. The Akunoura Engine Works were originally founded by the Shogun's Government in 1857, for repairing small war vessels owned by the Shogun, and were handed over to the present Government at the time of the Restoration. A large dry dock, now No. 1 Dock, was constructed, the patent slip at Kosuge was purchased, and the business became gradually established. The principal work done during the Government occupation was the building of a wooden steamer, the *Kosuge Maru*. In 1884 the whole works passed by purchase from the Government, to the present proprietors—the Mitsu Bishi Company—who started on this branch of business with only 800 men. The shipbuilding trade being quite insignificant at that time, the works made very slow progress, and an iron steamer of only about 200 tons was the principal vessel built in the three years after the purchase. This, however, was followed shortly afterward by three steel steamers each of 700 gross tons, and also in 1895 by a steel steamer of 1 530 gross tons, the *Suma Maru,* the largest steel merchant ship built in Japan at that time. Somewhat later the industry began to take on great activity, and in 1898 a 6 000-ton steel steamer, the *Hitachi Maru,** was turned out. Of late, the works have been very much improved by enormous extensions, most of the old shops have been rebuilt, many new buildings erected, and a large number of modern machines added. It has now a water frontage of about 8 000 ft., and the premises cover nearly 80 acres. There are three dry docks, measuring, respectively, 350, 510 and 714 ft. in length on the keel blocks, and a patent slip 750 ft. long on the rail, and also eight building berths ranging from 170 to 700 ft. Ships having a gross tonnage of more than 20 000 tons can be constructed by these works in one year.

Table 8 shows the general development of the works in the last ten years.

The Kawasaki Dockyard Co., Ltd.—This company, established in Kobe, was originally founded by the present Government in the early seventies, and belonged to the Industrial Department; it was afterwards sold to Mr. S. Kawasaki in 1886, being transferred again to the present concern in 1896.

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* The *Hitachi Maru* was torpedoed and sunk in June, 1904.

GENERAL PLAN OF
MITSU BISHI DOCKYARD AND ENGINE WORKS,
NAGASAKI

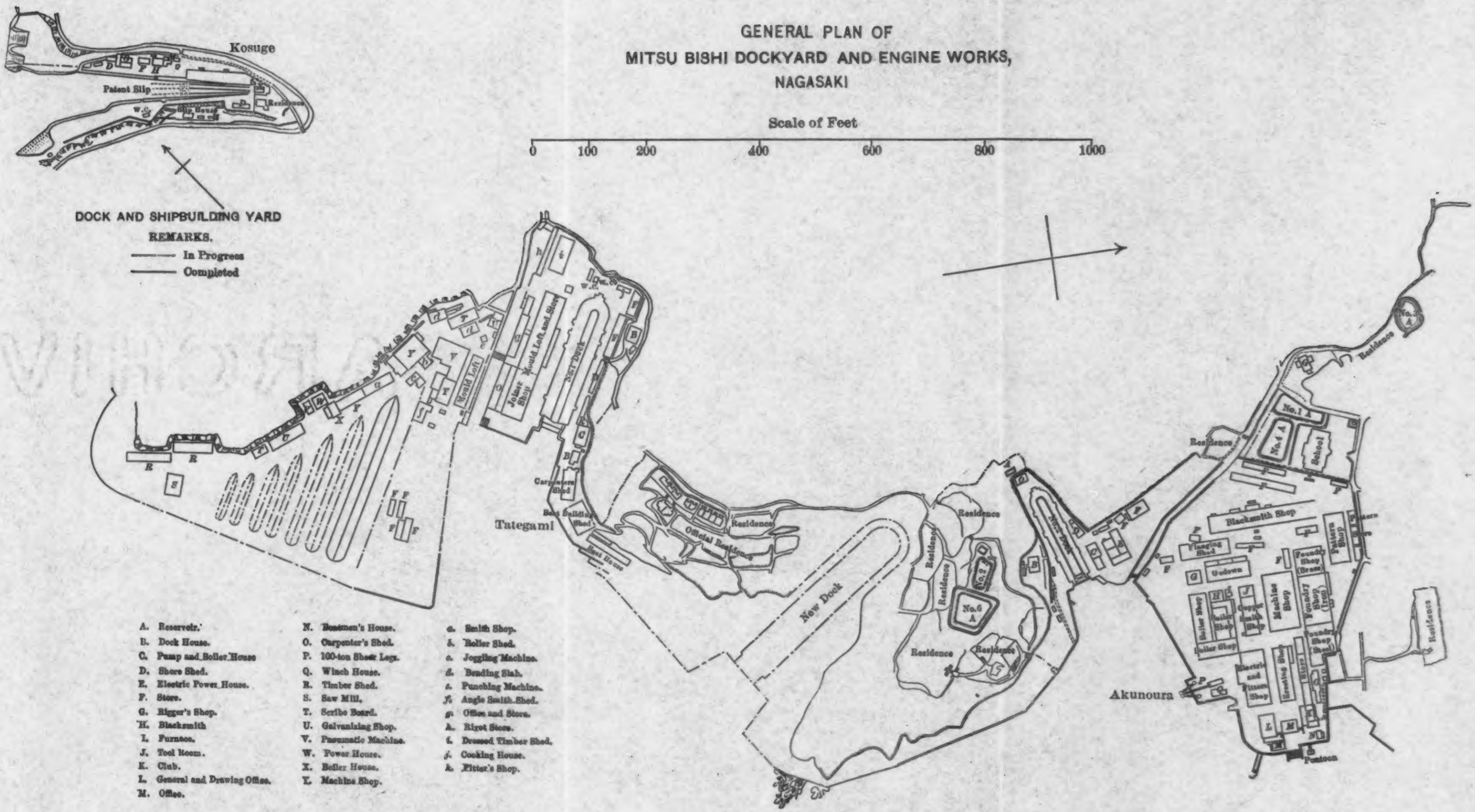


TABLE 8.

Year.	Ships built. Gross tons.	Engines built. Indicated horse power.	Number of men.
1894	82	40	1 450
1895	2 596	1 611	1 749
1896	79	242	2 607
1897	1 613	963	3 799
1898	7 703	4 225	3 430
1899	4 007	3 189	3 558
1900	11 333	13 519	3 792
1901	7 194	6 238	5 209
1902	15 807	13 336	5 193
1903	13 078	11 463	5 658
1903	(Building) 20 852	17 492	....

This yard, Fig. 4, has been extended only recently. When purchased from the Government it was a barren and unimproved piece of ground, covering nearly 9 acres, while now it has a water frontage of nearly 1 mile, and covers 35 acres of land, of which about 9 acres are occupied by shops and other buildings. It has been extended to nearly three times its original size in the last six or seven years. When under the Industrial Department, wooden ships of smaller sizes were chiefly built, besides the iron steamers *Asahi Maru* of 500 gross tons and *Yoshino-gawa Maru* of 380 tons. A few iron and steel vessels and many wooden ships were built by Mr. Kawasaki, and, since the incorporation of the present Company, more than forty steel vessels, varying from 100 to 2 300 gross tons, have been constructed. The principal vessels now in hand are the Chinese river gunboat, of 650 tons displacement, a light-house tender for the Corean Custom-House, 1 100 gross tons, a steam yacht for the Siamese Government, etc. In the last few years an enormous development has taken place, and the works can now build ships ranging in size from 1 000 to 7 500 gross tons. The graving dock, built in the permeable sand, with a concrete bed 12 ft. in thickness, supported by 8 400 piles driven underneath, is of the following dimensions:

Length on blocks	377 ft.
Width of entrance on bottom	51 "
Depth of water on blocks (at spring tide)	24 "

It took five years for its completion, and cost nearly 1 600 000 yen (about $800 000); it is really a fine specimen of engineering skill. This, with two slip docks constructed by the Government, re-

spectively, 600 and 394 ft. long, on the rail, gives facilities for the repair of ships of all descriptions, up to about 4 000 gross tons.

Table 9 shows the general development of the works since 1896.

The Osaka Iron Works.—The Osaka Iron Works, Dock and Shipbuilding Yard, Figs. 5 and 6, were started in 1880 by Mr. E. H. Hunter, with several Japanese partners; the latter, however, with-

GENERAL PLAN OF WORKS.
KAWASAKI DOCKYARD CO., LTD.
KOBE.

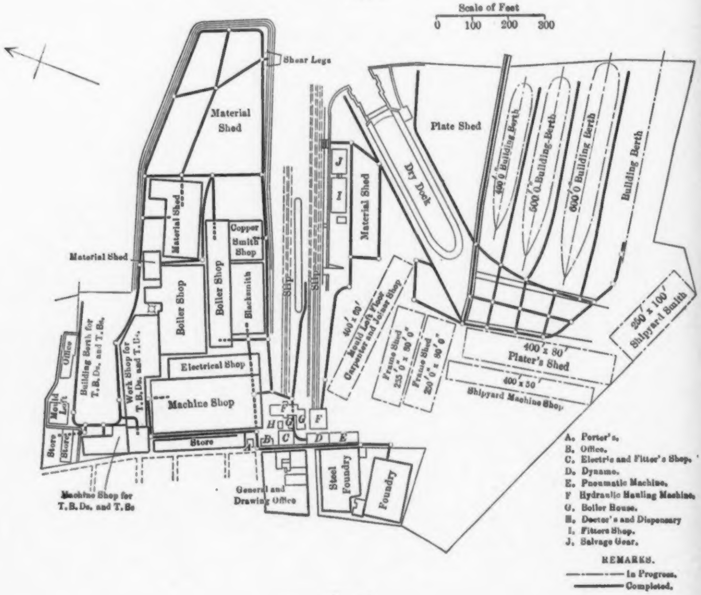


FIG. 4.

drew, one after another, being uncertain of the prospects of the enterprise at that period, and the whole establishment was left in the hands of Mr. Hunter. To meet the steadily increasing volume of business, the works made successive extensions, more especially after 1895, and in 1899 nearly 16 acres of land, with a water frontage of more than 1 000 ft., were secured at Sakurajima, ¼ mile from the mouth of the Aji River, and lying close to the new Osaka Harbour.

At this spot the shipyard for building iron and steel ships is now situated. Owing to small demand in the mercantile marine few vessels were constructed by the works prior to 1891, but from 1891 to 1903, 203 ships have been built. Of these, 83 were of steel, and the remaining 120 were wooden vessels of small tonnage.

TABLE 9.

Year.	Ships built. Tonnage.	Engines built. Indicated horse-power.	Number of men employed.
1896	1 050	1 200	1 800
1897	1 500	1 500	1 840
1898	1 000	1 720	1 860
1899	4 200	2 600	2 160
1900	4 960	6 769	2 200
1901	7 920	4 720	2 950
1902	8 520	10 870	3 365

The figures in the last two columns are only approximate.

The river at the spot where the shipyard lies, is 1 000 ft. wide and 14 ft. deep at present, thus restricting the size of the ships which can be built. Consequently, the attention of the management has been directed more to the building of vessels of smaller type, and a specialty has been made in the construction of dredges and shallow-

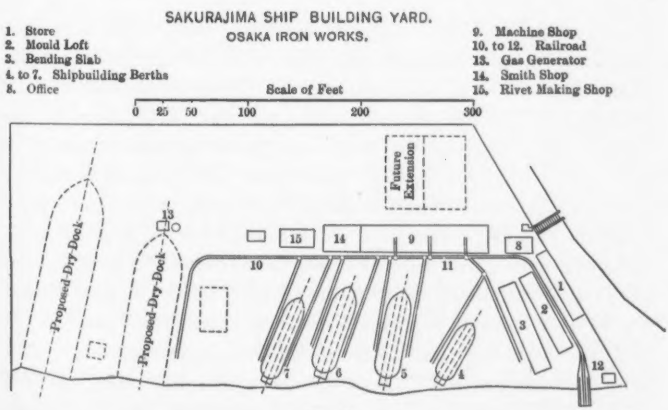


FIG. 5.

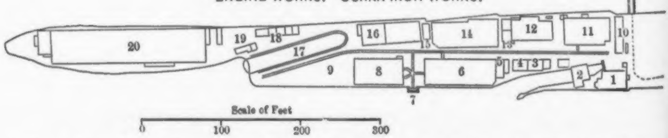
draft steamers. Bucket dredges, varying in capacity from 100 to 400 tons per hour, and shallow-draft steamers, 12 to 20 in. in draft, have been built during late years.

There are now eight building berths, ranging in length from 200 to 300 ft., but as soon as the Osaka Harbour improvements, now in progress, are completed, the depth of water at the site will be increased, enabling ships of much greater length and tonnage to be launched from the yard.

The yard for building wooden craft is on the other side of the river, and is available for tugboats and steam launches.

The Ishikawajima Shipbuilding and Engineering Co., Ltd.—This company, formerly called the Hirano Shipyard, was founded in 1876. The site was that of the old shipyard, where a sailing barque, the

ENGINE WORKS. OSAKA IRON WORKS.



1. Office. 2. Drawing Office. 3. Store. 4. Pattern Shop. 5. No.1 Prime Mover. 6. Machine Shop. 7. Shear Legs. 8. Erecting Shop. 9. Rail. 10. Main Store. 11. Foundry. 12. Smith Shop. 13. No.2 Prime Mover. 14. Boiler Shop. 15. Hydraulic Riveting Machine. 16. Copper Smith Shop. 17. Dry Dock. 18. Dock Yard Office. 19. Pumping House. 20. Pipe Foundry.

FIG. 6.

Asahi Maru, had been built in the late years of the Tokugawa Dynasty, by the Prince of Mito, one of the Shogun's family, and where also the first war steamer, the *Chiyodagata,* was built in 1861-65. The works, at their commencement, built many wooden sailing ships, steamers not being so popular in those days. With the intention of impressing shipowners with the superiority of steamers over ordinary sailing ships, Mr. Hirano built about a dozen small steam tugs (called the *Tsu-kwai Maru*) for sale or hire, and these were soon purchased by various shipowners. The shipyard had thus been gradually established, and in 1884 the Government Engine Works at Yokohama were purchased and incorporated with it. In 1885 the works were commissioned to build an iron gunboat of 615 tons displacement, the *Chokai,* this being the first order entrusted to Japanese private builders. She was completed in 1888, and the

works were then transferred to the present owners—the Ishikawajima Shipbuilding and Engineering Company.

To meet the pressing demand for ship repairing, after the sudden expansion of the Japanese mercantile marine in 1894-95, a new graving dock was started by the Ishikawajima Company at the port of Uraga, and was completed in 1898, being provided with complete shipbuilding facilities. The principal vessel built in this yard was the *Kotsu Maru,* of 1 500 gross tons, launched in 1901. Since then, not much new work of importance has been done. The shipyard was finally amalgamated with the Uraga Dry Dock Company in 1902. The vessels built in the works, in the period, 1877-1903, are as follows:

Type.	Number.	Gross Tons.
Wooden steamers	99	6 027
Steel steamers	9	3 703
Wooden sailing ships	24	3 385

Wooden Ships.—The building of wooden ships is still prevalent in Japan, as there is a plentiful and convenient supply of timber for the purpose. The most important trees in this respect are Keyaki (*Planeco Japonica*), Sugi (*Cedar, Cryptomeria Japonica*), Hinoki (*Fir*), and Matsu (*Pine*). But, owing to over-felling in old days, native timber has lately been getting scarce, and commands a very high price. During the last few years it has been gradually giving way to American lumber. Even under these conditions, wooden ships of the smaller sizes can still be constructed much more cheaply (as well as more quickly) than those of steel, and quite a number of them are launched every year. Of 49 vessels of more than 100 tons built in 1902, 42 of 6 281 tons out of a total tonnage of 16 373 were of wood. On more than one occasion quite recently wooden ships of more than 1 000 gross tons have been built. For most of the owners of wooden ships, however, cheapness is the only point coming under their consideration; this naturally produces a tendency to build ships of very weak and unseaworthy construction, and there are many instances of serious calamities arising from these defective conditions. In order to guard against them, the Japanese Marine Bureau (an institution corresponding to the British Board of Trade) issued, in 1900, a code of regulations for the survey and construction

of wooden ships, based on the rules of Lloyds and similar associations, and intended to bring unworthy shipowners and builders to a minimum standard in the construction of wooden ships.

For wooden shipbuilding in Japan, Osaka and Ominato, in Ise, have been most noted from very early days; some of the yards in these districts were founded for junk building more than 200 years ago, and, lately, have been improved by adopting western methods. Fujinagata and Ono, in Osaka, are among the largest of them.

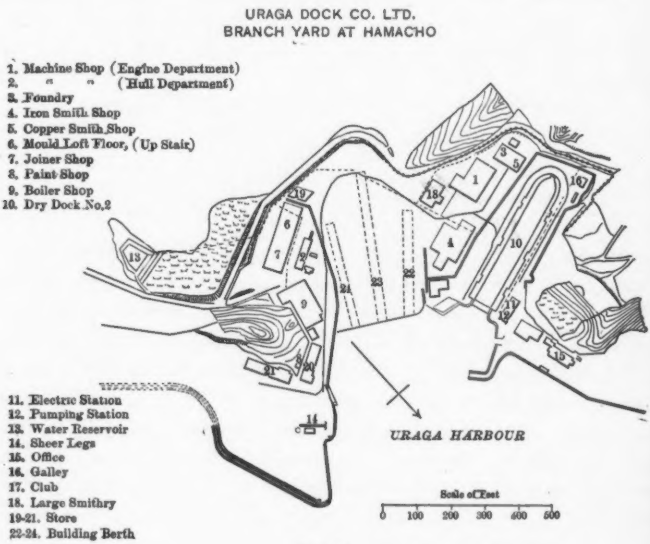


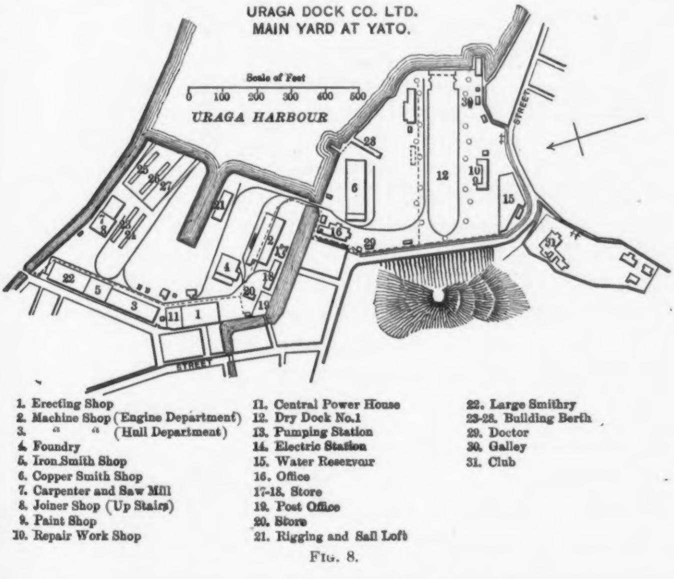
FIG. 7.

Fujinagata Shipyard commenced the building of a wooden sailing ship of western type, as early as 1869, following this by a steamer in the next year. They have built, in the last thirty-five years, 99 sailing ships, 112 steamers, and 41 barges and pontoons. Lately they have begun the building of steel ships, and have turned out a few steel barges.

Ono Iron Works and Shipyards, founded in 1879, can build ships of small size of both wood and steel, and, in the last twenty-five years, have turned out 4 steel steamers and many land and marine

engines. All these yards have been greatly extended in the last few years.

Dry-Dock Companies.—The necessity for repairing works being enormously increased, as the consequence of the sudden expansion of Japanese shipping after the war of 1894-95, many dry-dock companies were incorporated, including those at Yokohama, Uraga (Figs. 7 and 8), and Hakodate. These yards have one or two graving docks, of ample size to take the largest vessels in the country; and they also have appliances for the building of small vessels.



1. Erecting Shop
2. Machine Shop (Engine Department)
3. " " (Hull Department)
4. Foundry
5. Iron Smith Shop
6. Copper Smith Shop
7. Carpenter and Saw Mill
8. Joiner Shop (Up Stairs)
9. Paint Shop
10. Repair Work Shop
11. Central Power House
12. Dry Dock No.1
13. Pumping Station
14. Electric Station
15. Water Reservoir
16. Office
17-18. Store
19. Post Office
20. Store
21. Rigging and Sail Loft
22. Large Smithry
23-28. Building Berth
29. Doctor
30. Galley
31. Club

FIG. 8.

Table 10 shows the general particulars of the principal graving docks in Japan. The largest dock in the East is now under construction in the Mitsu Bishi Works at Nagasaki.

Floating Docks.—There are a few floating docks, capable of lifting the smaller war vessels of the Japanese Navy. A large floating dock for the Mitsu Bishi Company, now under construction, is of sufficient size to lift the heaviest vessels in the mercantile marine; it is to be stationed at Kobe.

TABLE 10.—GENERAL PARTICULARS OF THE PRINCIPAL GRAVING DOCKS.

Name of yard.	Locality.	Length, in Feet.		Width at Entrance, in Feet.		Depth on sill, in feet. Spring tide.
		Top.	Bottom.	Top.	Bottom.	
Mitsu Bishi Dockyard	Nagasaki	....	714.0	96	88	35.0
"	"	526.6	517.6	89	76	27.6
"	"	375.0	366.0	66	53.2	24.8
Yokohama Dry-Dock Company	Yokohama	552.1	516.0	95	75	29
"	"	422.0	377.1	61	46	27
Hakodate Dry-Dock Company	Hakodate	534.0	....	82	72	30.5
Uraga Dry-Dock Company	Uraga	497.0	494.0	69.6	59.7	27.6
"	"	456	448.0	65.0	53.0	25
Kawasaki Dockyard Company	Kobe	426	420	63.6	51.7	24.8
Bingo Dry-Dock Company	Bingo	410	395	57.0	52.0	24
Innoshima Dry-Dock Company	"	364	357	49.7	44.2	20.4
"	"	300	300	39.0	36.0	13.5

Dry docks more than 250 ft. in length on bottom	5	3 in Osaka. 1 in Tokio. 1 in Toba.
" " " " 200 ft. " " " "	3	1 in Osaka. 1 in Mikawa. 1 in Chikugo.
" " " " 100 ft. " " " "	12	4 in Osaka 4 in Iyo. 2 in Aki. 1 in Sanuki.
" " less than 100 ft. " "	2	in Iyo.

PATENT SLIPS.

Name of yard.	Locality.	Length, in feet.	Lifting power, in tons.
Mitsu Bishi Dockyard	Nagasaki	Total 750 Above water 300	1 200
Kawasaki Dry-Dock Company	Kobe	Under water 600 Above water 109	2 000
"	"	Under water 394 Above water 223.4	500
Hakodate Dry-Dock Company	Hakodate	Under water 520.7	1 400

GOVERNMENT DOCKS.

3 at Yokosuka; 2 at Kure; 1 at Sasebo.

General Development in the Last Decade.—The general development in the principal yards during the last decade may be considered under the following headings:

1.—Improvements in shipyard equipment and shipbuilding facilities;

2.—Reduction of time spent in building ships;

3.—Improvements in the process of shipbuilding;
4.—Some of the important works done;
5.—Labour conditions.

Shipyard Equipment and Shipbuilding Facilities.—All the principal yards are equipped in the western style, and they are importing every new machine from both Europe and America. Being later in the field than other nations, Japan has many advantages in avoiding experimental stages, and there is always less trouble in adopting the best of the kind. Thus, good inventions or improvements are much more easily and quickly applied in Japan than in places where everyone has been accustomed to older methods for years and years. Of late years, all the principal yards have been sending their engineers and constructors to Europe and America, one after another, to look around the different works and yards, to enquire into the methods they are adopting and to study the machines they are using. In that way the latest improvements are quickly imported. For example, the use of electricity in shipyards is very prevalent, and most of the principal naval and private yards are adopting or are about to adopt electric power in driving their machines in the different shops. The most complete electric installation can be seen in the Mitsu Bishi Dockyard, at Nagasaki, where there are two power stations, one at the Akunoura Engine Works, and the other at the Tategami Shipyard. The former is equipped with two sets of 225-kw. General Electric generators and one 500-kw. General Electric generator; there is besides one powerful battery plant consisting of 132 cells, of the Tudor type, capable of discharging 3 335 ampere-hours at 220 volts, and two 25-kw. Edison dynamos. The Tategami power-house is also well equipped with two 100-kw. Siemens dynamos, and one 25-kw. shunt dynamo. There are more than 120 motors, in both yards, ranging from 3 to 150 brake horse power, driving small machines by main shafts and pulleys, and most of the large shipyard machines by independent motors.

It is common for most of the yards to have generators in their own works, but in some places it is found more convenient to obtain power from the town electric light main. Wherever electricity has been used as the motive power it has proved very economical, and there is every tendency toward its becoming more popular.

Experiments with pneumatic tools have been made in both the Government and private shipyards, during the last few years, and such tools are now coming into very general use. In some of the principal yards powerful air-compressing plants are just being put in. One of the private builders sent a foreman to America to make an exhaustive study of the use of pneumatic tools, and since his return, he has been very successful in instructing the men how to get good results from their use.

Hydraulic plants have been adopted very extensively in the principal yards, for flanging, bending, joggling and punching plates, and also for riveting and hoisting.

The methods of conveying heavy materials have undergone great changes in the last few years, yet there are wide fields for further improvements, none of the recent material conveyors having been adopted yet in Japan.

Machines having the latest improvements, particularly those with labour-saving devices, have of late been largely imported, and the best of their kind can be found in any of the principal yards. In point of equipment and facilities, these can be compared with similar establishments of the highest reputation in Europe and America.

Reduction in Time.—The progress of the shipbuilding industry in the last decade has been very rapid, and, so far, very successful, and nothing is more apparent in this respect than the reduction in the time required to do similar kinds of work. According to practical experience in one of the private yards, a small steamer of 400 gross tons, built in 1894, took 9 months and 14 days from the commencement to the date of launching, while last year, a ship of similar type, a little larger in size, was launched after being in hand only 4 months and 14 days. Again, in the Naval Dockyard at Yokosuka, the *Akitsushima,* a third-class cruiser of 3 100 tons displacement, completed in 1894, took 48½ months for completion, while the *Niitaka,* a third-class cruiser of 3 400 tons, launched in November, 1902, took only 25 months. Similar facts can be observed in all the principal naval and private establishments. These reductions of time may be attributed partly to the extended use of machine tools, but must be due mainly to the skill of the workmen.

Improvements in Shipbuilding Processes.—One other cause for the enormous reduction in the time of production seems to be improved methods of laying-off. This is a point deserving great attention in western countries, and Japan has made wonderful progress in this direction. At present, in most of the principal yards, nearly all the deck plating and tank-top plating, and even some of the shell plating, are templated off the loft, and, in fact, the greater part of the templating is done before any work is commenced on the berths; that taken off the ship being restricted to both ends only. This method is made more necessary by the fact that, all materials being ordered from abroad, the greater part of the contract time is spent without doing anything, and when the materials arrive they generally come all at once; the work has then to be finished in a great hurry, giving every inducement to develop every possible means of minimising the time of production.

The Principal Works Done.—Japan has been spared the Iron Age, very few iron ships having been built. As has been stated before, the shipbuilding trade in Japan was quite insignificant at the time when iron was used extensively as shipbuilding material, and only about 15 or 20 iron steamers, ranging from 50 to 500 gross tons, were built, the last recorded being in 1893.

Semi-modern sailing ships are also unknown in Japan, the only two large steel sailing ships having been built specially as training ships for the Nautical College; the first of these, the *Tsukishima Maru* (238 ft. by 38 ft. 6 in. by 23 ft. 6 in.), fitted with an auxiliary screw engine indicating 300 h. p., was built at the Mitsu Bishi Dockyard in 1898. This boat having been lost at the end of 1901, another training ship, the *Taisei Maru,* 2 300 gross tons has been built at the Kawasaki Dockyard, Kobe, from the writer's design. She is a ship of quite unique type, being specially designed for the purpose, and it will not be quite out of place here to give an outline description.

She is 270 ft. long, 44 ft. wide, 26 ft. 9 in. deep, 4 300 tons in displacement at 20 ft. draft (moulded), and 2 300 gross tons; rigged as a four-masted barque, and fitted with twin sets of triple-expansion engines developing 940 h. p., capable of driving her at a speed of 10 knots with 1 500 tons of dead weight on board, equivalent to a sea speed of 9 knots when fully loaded. The reason she

is fitted with twin screws is to give her additional safety and better maneuvering power. She has accommodations for 13 officers, in 11 cabins, and 120 students, in 15 cabins. A large dining saloon, and library and reading rooms are provided for the sole use of the students. For the quarters of the students and the crew the ventilation is by artificial means through air trunks, with two 30-in. centrifugal fans actuated by electric motors. The refrigerating chambers, provision rooms and water tanks are of ample capacity for about 60 days' sailing without touching port; in addition she carries an evaporator and distiller of ample size.

The opening up of the interior of Japan has necessitated lately the development of inland navigation. Most of the rivers in Japan are barely navigable, being very shallow during certain seasons of the year; and the only means adopted until recently was to tow small barges and junks from the shore, but there is now considerable demand for light-draft steamers. In the early days of steam navigation, a few ocean-going paddle steamers, worked by large beam engines, were imported. These were used for several years in the coasting trade, but this type has now disappeared, having been replaced by screw steamers, while paddle steamers of the later types for river service have never come into general use in Japan. Some paddle steamers actually built were only of small size and of obsolete type, fitted with radial wheels, and naturally, they had very low efficiency.

One or two stern-wheelers were also built and tried, but were not successful owing to the lack of experience, and the present tendency is more toward the adoption of twin screws for light-draft steamers. The Osaka Iron Works have made a specialty of this type for some years past, and have already built some seven or eight steamers on which interesting experiments have been made. Thus far, they have obtained very good results. A general feature of these boats will be two or more propellers on the same shaft, in order to increase the blade area, this being made very much larger, in proportion to the immersed midship area, than in an ordinary screw steamer. The propeller tips project above still-water level, and, to lead up sufficient water on which the propellers may act, the ship's bottom at the stern is hollowed inward, forming a tunnel to cover the propeller disc. A boat (180 ft. by 10 ft. by 2 ft. 9 in.

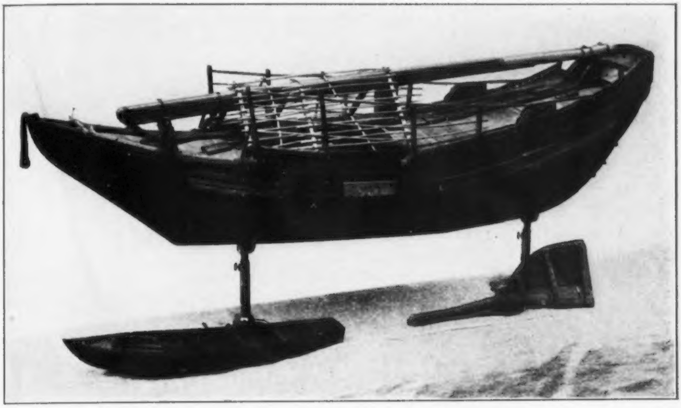


FIG. 1.—JAPANESE JUNK IN THE MIDDLE OF THE NINETEENTH CENTURY (ABOUT 70 TONS NET).

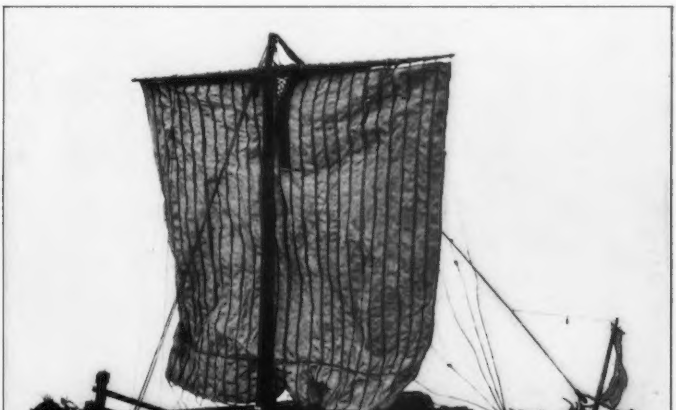


FIG. 2.—JAPANESE JUNK OF THE PRESENT DAY (ABOUT 100 TONS NET).

by 12 in.) was built for the purpose of making experiments under different conditions as to the pitch ratio, the blade area, and the form of the tunnels. From the results obtained, and also from trials of boats of similar type built in the yard, the following conclusions were reached:

1.—Each propeller should have a tunnel of its own;

2.—The ratio of the blade area to the immersed mid-section should be made large; there must be a certain limit to the size of the blade, but the limit has not yet been reached in the course of experiments tried at Osaka, in which the blade areas were increased to $\frac{1}{2.6}$ of that of the immersed mid-section.

Torpedo-boat destroyers (the *Harusame* class, of 375 tons displacement), built at Yokosuka in 1903, may be cited as illustrating the progress in the art of Japanese shipbuilding. These destroyers, four in number, were built from designs for which the Japanese Navy had to assume the whole responsibility. They are nearly of the same size as those ordered from abroad, but many important alterations have been carried out in these new vessels. According to the results of exhaustive trials, all have proved highly satisfactory, and in one, the *Asagiri*, a speed of 31.2 knots was obtained on the measured-mile trials, with normal loads on board.

Torpedo-boats ordered from abroad, have been sent out to Japan in pieces, and several of the private builders were asked to rebuild them. This gave valuable experience to those interested, and, shortly afterward, four torpedo-boats, two of the first-class and 28 knots, and two of the second-class and 24 knots speed, were ordered from the Kawasaki Dockyard Company, where most satisfactory results have been obtained.

The finest specimen of the work done can be seen in the *Hatsukaze*, a steam yacht of 80 gross tons, which was built for the Japanese Crown Prince, and completed in 1902, and also, in the *Nikko Maru*, of 5 500 gross tons, an Australian liner of the Nippon Yusen Kwaisha, launched and completed in 1903; they were both built in the Mitsu Bishi Dockyard, at Nagasaki, and have been neatly finished with the best specimens of Japanese fine arts. The former was fitted with a quadruple-expansion engine of 220 i. h. p.,

and Miyibara's patent water-tube boiler. The *Nikko Maru* was fitted with the largest engine ever made in Japan, having developed 6 780 i. h. p., in a single set, on the trial, giving her a speed of 17.8 knots, the highest speed ever attained by a merchant ship built in the country. The *Tango Maru,* of 7 300 gross tons, the largest in the Japanese Mercantile Marine, is now under construction in the same yard.

The shipbuilding industry of Japan is thus becoming firmly established, and gradually embarking upon foreign competition. This can be seen from the fact that orders from foreign countries have been given to Japanese builders on more than one occasion, the more important orders being a Chinese light-house tender of 724 tons, built by the Kawasaki Dockyard Company in 1902, a Chinese river gunboat, a Corean light-house tender and a Siamese steam yacht, now under construction in the same yard.

Labour Conditions.—Thus the art of shipbuilding has advanced greatly of late years, and its products are comparable with those of the western nations. It is altogether a different question whether Japanese shipbuilding can be considered at present as one of the national industries, or whether Japan can enter into competition in shipbuilding on even terms with the other maritime nations, in the future. The cost of production, in the case of warships, seems to be favourable to Japanese builders; but, for merchant ships, the case is quite different, the ships built in Japan being from 20 to 30% dearer than those contracted for abroad. This enormous difference in cost, in spite of the very low wages paid to workmen is mainly due to: First, the very low efficiency of Japanese labour; and secondly, the lack of shipbuilding materials.

Labour in Japan is decidedly very cheap when compared with that in Europe and America. The average journeyman's wages, in the case of shipbuilding, amount to little more than 60 sen per day (about 30 cents), although it has gone up from 50 to 60% in the last ten years. In the Government works, where the profits and establishment charges are not included, wages correspond to nearly 42% of the total cost of ships, in the building of a third-class cruiser, according to Admiral S. Sasow's statement made before the Japanese Society of Naval Architects in 1903, while simi-

lar figures for British dockyards are nearly 55% of the total cost. For merchant ships, however, the labour bill takes a rather higher percentage in Japan than for similar vessels built in England or other countries. This shows clearly the inefficiency of Japanese labour. According to experience obtained in one of the private yards, the labour bill, when expressed in terms of the cubic measurement of ships built, remained nearly constant, for many years, in spite of the gradual increase of wages during the period. This fact shows that the adoption of labour-saving machines and tools has a decided effect in reducing the cost of production; but, during the last few years, where no striking improvement has been made in the yard equipment, the labour bill has been going up gradually, although not in a similar ratio to the increase of wages.

Thus the different methods of inducing the workmen to exert their full powers have engaged the attention of those responsible in Japan, and have been tried lately in different places. The piecework system is now adopted extensively for certain classes of work in both Government and private yards, proving very successful so far. The premium system has also been in use in one of the private yards for many years past, to the great satisfaction of both men and employers. In this special yard, before giving out a certain job, the yard managers have to decide the number of days required to complete it, and if the assigned work is finished in less time, 40 to 50% of the gain is given to the men over and above the wages for the hours worked, and if finished after the time the men are paid according to the actual number of hours worked.

There is no regular system for apprenticeship throughout Japan, each yard having a system of its own, but, generally speaking, boys who have finished their course in an elementary school (four years at least), are placed at whatever trade seems most suitable, in the managers' discretion, and, when they have sufficient experience at the trade, they are paid a journeyman's wages, there being no regular interval for them to serve as apprentices. There are no premium apprentices in Japan, and graduates coming from the universities, or other higher technical schools, have no difficulty at present in getting appointments in shipyards, as leading draftsmen or undermanagers. This is partly due to the lack of trained hands in all

yards since the enormous and sudden expansion of the trade, but it will soon become more common for young graduates to enter as apprentices for some years.

Trade unions are still unknown in Japan, and any disputes between employers and employees are settled by mutual agreement. Strikes or agitations are practically unknown, except in a few cases where there has been agitation against some unpopular manager, just as in the schools there is often agitation against an unpopular teacher. Thus there are no fixed wage scales, common to the same trade or district; but natural competition keeps them at a fairly uniform rate all over the country.

No Government regulations, with regard to working hours, compensation, etc., have as yet come into force, although they have been under serious consideration for some years past. Each shipyard has its own system of relief fund and pensions; the system in force in the Mitsu Bishi Works at Nagasaki, being most complete in its nature, will be cited as an example. Each employee has to contribute a certain proportion of his wages on each pay day to the relief fund, and the employer contributes an equal amount. The benefit accruing to the workmen varies from 2 500 to 50 yen ($1 250 to $25), according to the class and the rate of wages, and this is applied to the families of those who have died from accidents while on duty, and to those incapacitated through injury received at the works; those who retire from old age or other legitimate reasons are also entitled to receive pensions, according to their grade and number of years of service. Some of the works have their own hospitals for accidents, while others have special arrangements with some hospital in town; in both cases the men are treated at the expense of the employers.

Shipbuilding Materials.—Of the materials of a third-class cruiser completed in 1897, nearly 70% by cost, according to Admiral Sasow's statement, was imported, or nearly 47% of the total cost of the ship was supplied from abroad. These figures are very much higher in the case of a merchant ship, where the cost of materials is more predominant than in warships; and if the freight, commission, and custom dues taxed upon these imported materials are considered, there is no wonder that ships built in Japan cost more than those ordered from western nations. Again, of imported materials, iron and steel are the most important, being in the case of

the third-class cruiser previously cited nearly 43% by cost of the total materials used, or nearly 67% of the materials imported, and in the case of merchant ships of moderate size, more than 60% of the total material used.

The want of iron and steel at present is thus the greatest drawback to the development of Japanese shipbuilding; it also causes great inconvenience in prolonging the time of completion, as the delivery of material involves a delay of at least five or six months. To remedy this defect, the importance of inaugurating the iron and steel industry in Japan had been recognised for a long time, and the Imperial Government, having decided to start on this industry, has made very elaborate and exhaustive investigations with regard to the quantity and nature of iron ore obtainable in Japan, the manufacture of pig iron and steel, and also the organization of the works. Being satisfied with these preliminary investigations, the scheme of the steel works was submitted to the Diet in 1896-97, and passed unanimously, and the steel works were commenced in 1897 at Yawatamura, near Moji. The works comprise two large blast furnaces, each capable of producing 130 tons of pig iron every day (one complete and one now under construction), six Siemens-Martin furnaces, 25 tons each (four working and two to be completed in 1905), and two 10-ton Bessemer converters. When working under favourable conditions 90 000 to 120 000 tons of pig iron per annum will be produced. The steel is produced by the basic process, and, in the course of a few months, it will be possible to roll steel plates of any size up to 1⅝ in. by 96 sq. ft., angles up to 7 by 3½ in. or 6 by 6 in., and channel and Z-bars up to 10 in. deep. Smaller plates, angles and rails have been rolled continuously during the last three years. The quality of the steel is such as to be capable of withstanding all the tests required by the British Admiralty, Lloyds, and similar institutions; the chemical composition of the steel for shipbuilding purposes, taking a mean of seventy-one charges, is as follows:

Carbon	0.24
Silicon	0.02
Phosphorus	0.04
Sulphur	0.05
Manganese	0.56

Different qualities of steel, also with different degrees of hardness, can be and have been rolled. When the steel works are in full swing, 90 000 tons of steel will be produced yearly (40 000 tons in 1904), and the plates and bars used for shipbuilding will be freely supplied at home.

There are, besides, a few steel foundries, six in all, mostly of small size, for making steel castings and ingots for forgings used in various parts of engineering structures. Most of these have been started lately, either as independent establishments, or as part of shipyards or engineering works. One in Osaka, founded in 1899, the Sumitomo Steel Works, has two Siemens acid furnaces, of 5 and 3.5 tons, respectively, and supplies cast-steel stern posts, shaft-brackets, rudder-frames, anchors, etc.; the total output in two years, ending in June, 1903, was 3 250 tons. A steel foundry in Yokosuka Dockyard was started in 1892 and has three Siemens furnaces of from 2 to 6 tons capacity. One in the Kawasaki Dockyard, with a furnace of 6 tons capacity, has been working since 1902, while one in the Mitsu Bishi Works has just been completed; they are to supply small steel castings for various parts of the hull and engines.

The steel works at the Kure Arsenal have been founded for the sole object of supplying steel war materials, such as guns, shells, etc., and only the necessary special kinds of steel are made there. These works are replete with powerful hydraulic forging presses, large steam hammers and all other necessary appliances. Lately they have turned out heavy guns of the latest type, and will soon be capable of completely arming a battleship. An armour-plate rolling plant is to be laid down in the works.

Besides iron and steel, there are still a great many items, such as deck machinery and small fittings, imported from abroad, but their manufacture is neither started nor even attempted in Japan, and it will take some time yet before the country can become perfectly self-supporting in its shipbuilding industry.

Progress of Marine Engineering.—Marine engineering has made similar progress in the last forty years. In the early days, the engines built were all of the single-cylinder or two-cylinder high-pressure type, and the earliest compound engine on record was built in the Osaka Iron Works in 1882. The first triple-expansion

engine used for actual service was for the *Kamogawa Maru,* built by the Kawasaki Dockyard Company in 1889. Quadruple-expansion engines, to realize still greater economy, have been fitted in the *Wakamatsu Maru, Daiya Maru* and *Hatsukaze,* built at Nagasaki in 1902.

As to marine engineering in the Japanese Navy, the following abstracts from the statement made by Engineer Admiral J. Miyabara, at the Osaka meeting of the Japanese Society of Naval Architects, in 1903, will be interesting in this connection:

"The engines of the *Takao,* a third-class cruiser of 1 750 tons displacement, designed in 1886, the ship being launched at Yokosuka in 1888, were considered the best types of that day. Comparing this machinery with that of the *Otowa,* a third-class cruiser of 3 000 tons displacement, launched from the same yard in 1903, we may see the progress made in twenty years. In the *Otowa,* the indicated horse power per ton of machinery is about 12, in the *Takao,* only 7; and the displacement per ton was more than .3 as against 1.3. The piston speed of the *Otowa* is 1 000 ft. per min.; that of the *Takao* only 533. The boilers of the *Otowa* are of the water-tube type of Japanese Admiralty design; pressure, 200 lb.; indicated horse power per ton of boiler, 32. The boilers of the *Takao* were of the ordinary return-tube type, 70 lb. pressure, indicated horse power per ton, 1.3."

Water-tube boilers were recently introduced in the Japanese Navy, Belleville and Niclausse for the larger tubes, and Yarrow, Thornycroft and Normand for the smaller tubes, are extensively used. A water-tube boiler designed and patented by Admiral Miyabara, has been authorized lately by the naval authorities to be included among those accepted for the Japanese Navy. This boiler is remarkable for the complete circulation of water therein, a fact supported by repeated experiences in practice. There is also a type of boiler, designed by the Admiralty, and adopted in many ships of the later build.

Technical Education.

The School of Naval Architecture at Yokosuka.—The system of education for naval architects in Japan has undergone many important changes in successive years, just as the systems for other branches of science, from the early days of Meiji. The oldest

institution of its kind was that started as early as 1865 in Yokosuka. The school of naval architecture, founded in connection with the naval dockyard there, was intended to educate naval constructors. The instructors were mostly Frenchmen employed in the dockyard, and the course of study, although it changed from time to time, covered about three years, and comprised Mathematics, Physics, Chemistry, Drawing, Naval Architecture, Engineering, etc., all after the French system. The youths who had qualified themselves by attending the practical works for a certain number of days, were admitted free, and they were also sent to the shipyard during school hours to get accustomed to practice. This school stood for nearly fourteen years, when it was suspended. Most of the successful graduates were sent to France after their graduation, to complete their technical as well as their practical training, and to-day they are occupying important positions in the Naval Construction Corps of the Japanese Navy.

The University.—The university training of naval architects as a part of the State system of education, was commenced in 1880, under the Mechanical Engineering Department in the late Kobudaigakko (Imperial College of Engineering). The first student graduated in 1883; and, in 1886, after the organization of the present University of Tokio, a regular course in naval architecture was established as a department in the College of Engineering, 130 students, including those of the Kobudaigakko, having graduated from this department during the last twenty-one years. Under the present system, the course of instruction extends over a period of three years; any student who has completed a course of general training extending over fourteen years—six years in an Elementary School to which he is admitted after attaining the age of six years, five years in one of the Middle Schools, and a three-years' preparatory course in a Higher School—is eligible for admission to the University. The curriculum is as follows:

First Year Course.—Higher Mathematics, Dynamics, Applied Mechanics, Hydrostatics and Hydrodynamics, Thermodynamics, Heat Engines, Mechanics, Metallurgical Technology, Naval Architecture, Ship and Marine Engine Drawing, etc.;

Second Year Course.—Naval Architecture, Marine Engineering,

Electrical Engineering, Hydraulic Machinery, Technology of Arms, Industrial Economy, Naval Architecture, Design and Drawing;

Third Year Course.—Naval Architecture, Design and Thesis.

Owing to the great expansion which has taken place within recent years in the shipbuilding industry of Japan, there is a pressing demand for young men, thoroughly trained as theoretical naval architects, and at the same time capable of taking charge of any of the branches of practical work. In the older industries of Europe and America this practical training is almost entirely obtained by many years' work in actual service after the completion of the theoretical studies of the University; but in Japan there is not time for this, and so the aim of the University is not only to cover the whole of the theoretical and higher side of the subject, but also to give the maximum possible amount of practical information and training. This is accomplished by requiring the students to devote a large portion of their time to actual designing in the drafting-room, and with the willing co-operation of the Navy Department and private shipbuilders of the country, by sending the students to work in the various shipbuilding establishments during fully eight months of their course. The time so spent is occupied partly in making sketches, but principally in taking part in one or more of the practical branches of the shipyard work. The students are thus enabled to fill satisfactorily important positions on the active staff of the various dock and shipyards, and no difficulty is found in securing such posts for successful graduates.

The drafting-room work at the University covers in the first year, drawing and fairing a ship's line, preparation of a midship-section in accordance with Lloyds and other regulations, calculations of displacement and metacenter, plotting of curves, etc.; in the second year, groups of two or three students work together and prepare all the principal working drawings for an ordinary merchant or war vessel, making all the necessary calculations and curves and working to outline specifications supplied by the University staff; during the third year, each student has to prepare a complete and careful set of plans of some original design, and also to write a thesis, not necessarily original, upon any subject within the scope of naval architecture.

The graduates, totaling 130 in July, 1904, are at present occupied as shown in the following list, from which it can be clearly seen how university education has proved useful in promoting the shipbuilding industry of Japan:

Naval constructors	35
Surveyors of the Marine Bureau of Japan	20
Superintendents of shipping companies	11
Employees in private shipyards	36
Consulting naval architects	6
Professors and instructors in naval architecture	6
Post-graduates in University	8
Studying shipbuilding abroad	2
Serving in army	4
Deceased	4

The number of students has increased lately, and new class rooms in a two-storied building of 360 tsubo (1 tsubo = 6 ft. square), were completed in July, 1903, with accommodation for 75 students, 25 in each year; but unfortunately this building was destroyed by fire on June 3d, 1904, and a new building is now in the course of construction.

Osaka Higher Technical School.—The want of competent draftsmen and foremen in shipyards having been perceived for many years past, the Government organized a shipbuilding class in the Osaka Higher Technical School in 1900, with a standing considerably below that of the University. Any boy who has finished a general training in a Middle School is entitled to enter this school, and has to stay for three years. The school has to deal more with the practical side of the subject, and the curriculum comprises the following courses: Mathematics (Elementary Calculus), Applied Mechanics, English, Physics, Chemistry, Drawing (Freehand and Geometrical), Mechanical Engineering, Practical Shipbuilding, Elementary Theoretical Naval Architecture, etc. Every precaution is taken to give the necessary amount of practical training. The school has small engineering workshops, complete in themselves, and students have to work there during school hours, while during their vacations they

are sent to one of the shipyards to observe or to take part in some portion of the work of the yard.

Twenty-two pupils have been graduated from this school during the last two years, and the majority are employed in either the Government or private shipyards.

Foremen's Schools.—There are, besides, six elementary technical schools with a still lower standing in the various shipbuilding centers; they are all based on somewhat different systems.

Foremen's School at Yokosuka.—The Foremen's School at Yokosuka, in connection with the dockyard, has existed for more than twenty years, and is for the training of young hands in the naval dockyards. Any one who has served in one of the dockyards for at least three complete years is admitted after an entrance examination. The course of instruction extends over three years and includes Mathematics (Elementary Trigonometry, Algebra, and Plane Geometry), English, Elementary Physics and Chemistry, Applied Mechanics, Drawing, Practical Shipbuilding, Calculations relating to Displacement, Metacenter and Stability, etc. The students have to work in different departments in Yokosuka Dockyard, for every half day during these three years; after graduation they have to go back to the dockyard where they served their time, and subsequently are appointed to positions as foremen, or as assistant constructors (corresponding in rank to Warrant Officers). There are also possible openings for the best of them as they have the chance of being appointed, by selection, as constructors.

Koshu-gakko.—The Koshu-gakko or Foremen's School at Tokio, was founded in 1887 by a private corporation of University graduates, with funds raised by public contribution, especially from those in direct connection with the industries of Japan. The school comprises the different sections of engineering sciences, shipbuilding being one of the sections. This was originally intended to give some scientific knowledge to young men employed in some of the works; but in reality, the great majority of the students are those coming fresh from the Elementary Schools. The course of instruction extends over two years and a half, the first year being a preparatory course, as a prelude to the technical training in the remaining year and a half; the latter includes practical shipbuilding and an

outline of theoretical naval architecture. Although there are no regular hours assigned for practical work, students are sometimes taken around the shipyards in Tokio, or the suburbs, to see the routine of work in the different yards. The total number of students graduated in the last 16 years is 126, and they are mostly employed in the drafting-rooms of different shipyards throughout Japan.

Ominato Apprentice School.—The Evening Apprentice School at Ominato, a small village noted for wooden shipbuilding from early days, was founded in 1896 by the City Corporation, being subsidised by the Central as well as the Local Government. It gives technical training to boys desiring to enter their fathers' profession. Any boy who has attained twelve years of age, and who has completed four years' training, at least, in an Elementary School, is admitted free. The course of study extends over three years, is of a thoroughly practical nature, and includes an outline description of shipbuilding, shipyard work and shipbuilding materials, besides the usual course of English, Mathematics, Physics, Chemistry, Drawing, etc. All classes meet in the evening, and the boys are sent to work as apprentices in one of the yards during the day. The majority of graduates, totaling 45 during the last five years, are employed in the shipyards of that district and are found very useful to their employers. There are 90 students in the school at present, of an average age of 14 years and 9 months.

The Mitsu Bishi Technical School.—The Mitsu Bishi Technical School, founded in connection with the Mitsu Bishi Works by Baron Iwasaki, the owner of the works, is intended to give the necessary scientific training for those wishing to enter the shipbuilding and engineering trades, and is free to the general public. Boys over ten years of age, who have passed the four years' course in an Elementary School, are admitted free, and have to stay five years. The course of instruction covers Mathematics, English, Physics, Chemistry, Drawing and Japanese. Special attention is paid to teaching English; and much time is devoted to it, as it is considered most essential, in the future, for engineers and shipbuilders to master, at least, one of the foreign languages. In their fifth year, the students are taken around the works in order to become acquainted with practical operations, and are also given an elementary course in Steam Engineering and Mechanism.

The boys who have finished the proper courses are allowed to enter the different departments of the Mitsu Bishi Works as apprentices for another five years, although this is by no means compulsory. During their apprenticeship a few lectures on more advanced sub-

MINIMUM AGE OF STUDENTS IN DIFFERENT SCHOOLS.

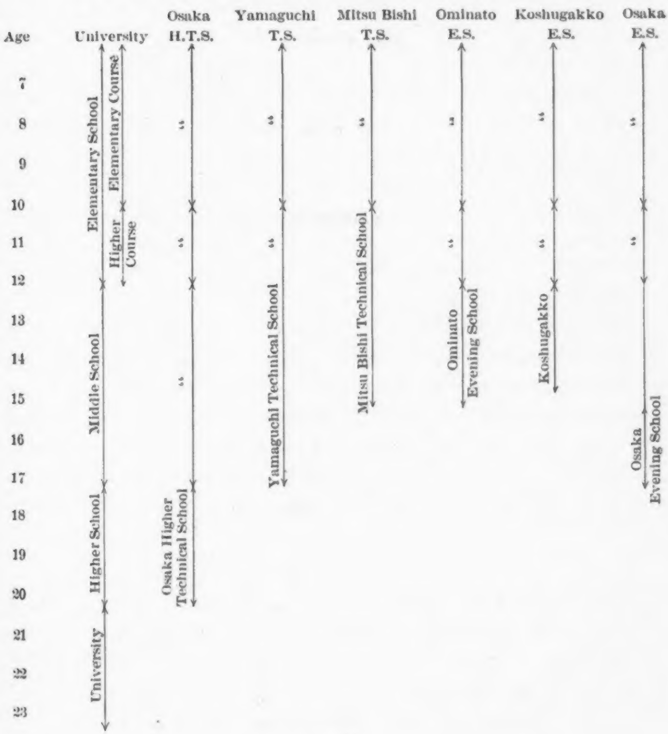


FIG. 9.

jects, such as Applied Mechanics, Naval Architecture, Marine Engineering, Hydraulics, Electrical Engineering, Higher Mathematics, are given about four hours a week, in the morning. Special classes are also held for general workmen who desire to acquire some scien-

tific knowledge. The instructors of the school are mostly graduates from the Imperial University, or from the Higher Technical Schools, who are employed in the Works.

The school has accommodations for 50 boys in each year, totaling 250 in all. At present (1904), there are 232 boys besides 100 apprentices who attend the special classes already mentioned, in the morning before they go to work. The first students of this school, 22 in number, were graduated at the end of March, 1904, and most of them entered the Works to serve as apprentices, while a few went to technical schools of higher standing to complete their theoretical training. The average age of boys graduating this year was 17 years and 1 month.

Yamaguchi Technical School and Osaka Evening School.—There is also a Technical School at Yamaguchi, started in 1903 by the Local Government, and an Evening School, similar to the one in Tokio, was founded in Osaka in 1902, both being intended to promote the shipbuilding industry.

As most of these institutions are comparatively new, it is not easy to determine their exact value, yet there is very little doubt that, in these days when there is a pressing demand for skilled workmen with some scientific knowledge, those boys with preparatory technical training, who afterward acquire sufficient practical knowledge, will, in the future, be of value, not only to the works employing them, but to the national industry of shipbuilding.

CONCLUSION.

As the conclusion to this paper, it will be interesting to add a few words from a foreigner's point of view on the future of the shipbuilding industry of Japan; and in this respect, the writer cannot do better than give the views of F. P. Purvis, Professor of Naval Architecture in the Tokio Imperial University, who has had thirty years' experience in the trade, and who has been in Japan for fully three years. He writes as follows:

"As to the future of Shipbuilding and Engineering in Japan many interesting questions present themselves. Apart from the time occupied by the workmen in accomplishing what is assigned to them, there seems to be no lack on their part of the power to

produce good work, as good indeed as can be produced in any country. Whether or not the physical strength of the Japanese is, man for man, as great as that of taller peoples, the question has but a partial bearing on the art of shipbuilding; there are indeed those who contend that in such work as riveting, the Japanese workmen can knock down a keel or sheer strake rivet of the largest size as thoroughly as his fellow workmen in other countries; but in most cases, at least, it is a matter of skill more than of brute force, and, in this respect, the Japanese workman has every advantage possessed by his rival. No doubt at the present time difficulties exist; a want of appreciation of what in the other countries is regarded as essential to good work is often discernible; steelwork is more roughly finished, especially in such portions as require local heating; the details of fitting riveting dressing, especially in out-of-the-way corners are more liable to be slurred; again, woodwork is imperfect from insufficient attention to seasoning; jointing is imperfect, or in some other way is open to criticism; the painter, too, has not yet acquired the full art of covering up the defects of his predecessors. Similar remarks apply to all the branches connected with shipbuilding and engineering; but, in all these matters, it seems only necessary to set before the workmen an ideal that has been reached by others, and they also will realize it; this of course involves good superintendence, a determination to be content with nothing short of the perfection aimed at. Good work thus becomes a matter of detail, and the details are ever receiving the constant attention of those responsible.

"The future then of Japanese shipbuilding does not depend upon the power or skill of the builders, either employers or employed, to produce good work. From the present outlook it rests upon economic considerations, and this in two respects: first, there must be a demand for ships in the country, and, next, there must be economic conditions that allow of their construction. As things are now, large mail companies like the Nippon Yusen Kaisha, indeed large shipping concerns at all engaged in foreign trade, could not exist without large subsidies. Again in the matter of building, if the builder is to compete with foreign builders he must get some assistance. Should a cheese-paring Government come into power, and see fit to withdraw the subsidy, either for the running of steamers, or for the building of them, modern shipbuilding would practically cease in the country, and foreign trade in home bottoms would be lost. Small coasting steamers would indeed still be run, as they are protected by the exclusion of foreign steamers from such service; possibly also, for various reasons, many of them would be built at home instead of being purchased abroad; but the result would be a large diminution of the building at present practised. Some

day the subsidies may be reduced without injury; especially when steel is made in sufficient quantities at home will the circumstances be materially altered, but that day is not yet, and none but a bold man would attempt to prophesy the time of its arrival. In the meantime the subsidies given are liberal, and owners and builder receive not a fortune but a competence; owners, notwithstanding the war, are adding to their fleets, and builders (the three best equipped, in particular) have their stocks fairly well occupied, with prospects of more orders to come."

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 47.

NAVAL ARCHITECTURE.

EXPERIMENTS ON VIBRATION OF THE JAPANESE TORPEDO-BOAT DESTROYERS, *HARUSAME* AND *HAYATORI*.*

By F. P. Purvis, F. Omori, S. Terano, and C. Shiba.†

These experiments took place on the 20th of March, and the 4th and 11th of June, 1903, at Yokosuka. They were made by permission and with the assistance of the Japanese Navy Department. Their object was (1) to obtain accurate records of vibrations in the two vessels named, at different speeds, and (2) to test the applicability, for this purpose, of the vibration measurers used for other purposes by the Seismological Institute in the Science College of the Tokio Imperial University.

* Condensed, by permission, from the report presented to the Engineering College of the Tokio Imperial University, but not yet published. It is regretted that the original diagrams of the vibrations were unfortunately destroyed, shortly after the completion of the following analysis, by the fire in the Naval Architecture Department of the Engineering College.

† Professors at the Tokio Imperial University, Japan.

Dimensions of Vessels.—The leading particulars of the vessels are as follows:

	Harusame.	*Hayatori.*
Length between perpendiculars...	227 ft.	227 ft.
Breadth moulded...............	21 ft. 6 in.	21 ft. 6 in.
Mean draft, on trial............	6 ft. ½ in.	6 ft.
Displacement, on trial...........	378.5 tons.	375 tons.
Maximum speed, in knots........	28.89	29.89
Indicated horse-power (metric), at maximum speed..............	5 250	5 897
Revolutions, at maximum speed..	370	383

The machinery consisted of two sets of 4-cylinder triple-expansion engines; cylinders, 20½ in., 30½ in., 2-34 in. by 18 in. stroke, with longitudinal dispositions and crank angles as shown in Fig. 11; two propellers, 3-bladed, 7 ft. diameter by 9 ft. pitch.

The vessels were built at Yokosuka. With their sister vessels, *Murasame* and *Asagiri,* also constructed at Yokosuka, they were the first torpedo-boat destroyers built in Japan, for the design of which the Navy Department assumed the whole responsibility.

A general indication of the appearance of the vessels is given by Fig. 10. On this figure the position of the instruments used is also indicated.

Vibration Measurers.—The vibration measurers used were almost the same as those previously used by one of the writers in the measurements of vibrations of railway bridges and carriages;* they were the ordinary horizontal-pendulum and vertical-motion seismographs, with the friction much reduced, and the periods of free oscillation of the steady masses sufficiently lengthened. The recording cylinder moved with a circumferential rate of about 1½ to 3 cm. per second. The diagram thus obtained indicated the individual vibrations of the vessel, which can usually be distinguished from the effects due to rolling and pitching. The mechanical details of the two instruments, which had separate recording cylinders, are shown in Plates III and IV. The general appearance of the instruments is given in Plate V, Figs. 1 and 2.

* F. Omori: "On the Deflection and Vibration of Railway Carriages," and "Application of Seismographs to the Measurements of the Vibration of Railway Carriages." Report, Earthquake Investigation Committee, Nos. 9 and 15.

TORPEDO-BOAT DESTROYERS
HARUSAME AND *HAYATORI*

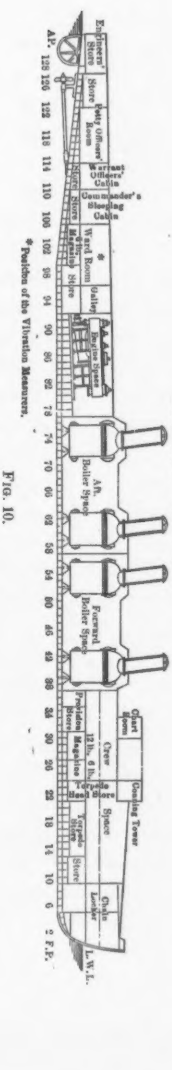
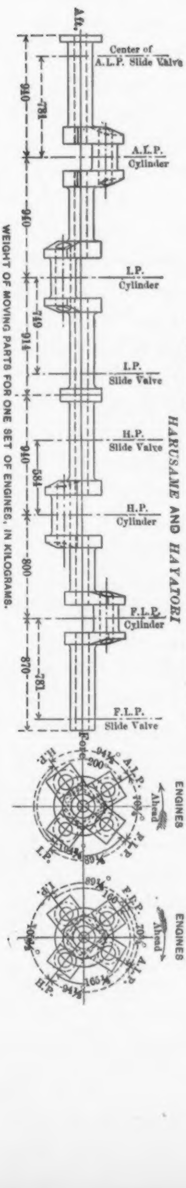


FIG. 10.

CRANK DIAGRAM OF THE TORPEDO-BOAT DESTROYERS
HARUSAME AND *HAYATORI*



WEIGHT OF MOVING PARTS FOR ONE SET OF ENGINES, IN KILOGRAMS.

Weight of each item:	H.P.	I.P.	L.P.
Piston	49	88.3	100
Piston Rod	182.2	19.5	116
Connecting Rod	229	229	146.1
Slide Valve	71.5	92	73
Valve Rod	25.5	25.5	25.5
Eccentric Rod	48	48	48

FIG. 11.

Vertical Vibration Measurer (Plate III).—This is the vertical-motion seismograph of the Gray-Ewing type, with some modifications. *a* is a stout cast-iron stand, about 60 cm. in height, fixed by two bolts, *b*, to a strong rectangular wooden base-plate, *c*, about 30 by 60 cm., on which the recording cylinder, *d*, is mounted. The steady line is the central axis of a small horizontal metal cylinder, *e*, about 1 kg. in weight, which is properly fixed at the end of a horizontal bar, *f*, by a screw. The bar, *f*, is about 30 cm. long, and its end half, *f f*, consists of a solid aluminum rod, fixed to the point of a brass triangular plate, $f f_2$, whose base is turned towards the cast-iron stand. The rod, *f*, is maintained in the horizontal position by being kept against the points of two fine steel screws, *g g*, fixed to the stand, and by being pulled upwards with the two helical springs, *h h*. The latter are suspended from the top of the stand by two vertical screws, *i i*. The lower extremities of the two springs are firmly attached to the ends of a small horizontal brass rod, *j*, which is at right angles to the rod, *f*, and is kept at a little distance below the latter by another fine steel screw, *k*, fitting into a conical socket of hardest steel at the middle of *j*. One of the two screws, *g g*, fits also into a conical socket of hard steel, while the other fits a **V** groove, also of hard steel, both fixed on the brass plate, $f_1 f_2$, near its base. The screw, *k*, serves, by its adjustments, to set the weight, *e*, in a neutral equilibrium.

The writing pointer is made up of a lever, whose two arms, $l\,l_1$ and $l\,l_2$, are bent at right angles to each other, and whose fulcrum, *l*, consists of a small horizontal steel axis pivoted in the conical sockets of two small horizontal screws; these screws are carried by a bracket, which is properly mounted on a wooden stand rising from the base plate, *c*. The horizontal arm, $l\,l_1$, is a thin brass fork, within the two limbs of which a cylindrical axis fits exactly, forming the prolongation of the central line of the heavy mass, *e*. The writing index, l_3, hinged to the lower end, l_2, of the vertical arm of the lever, consists of a steel pen. The center of gravity of $l_1 l\, l_2$ is brought almost exactly to the fulcrum, *l*, by means of two small counterweights, so that the pointer has practically no proper oscillation.

The record is taken in ink on a white band of paper, wrapped

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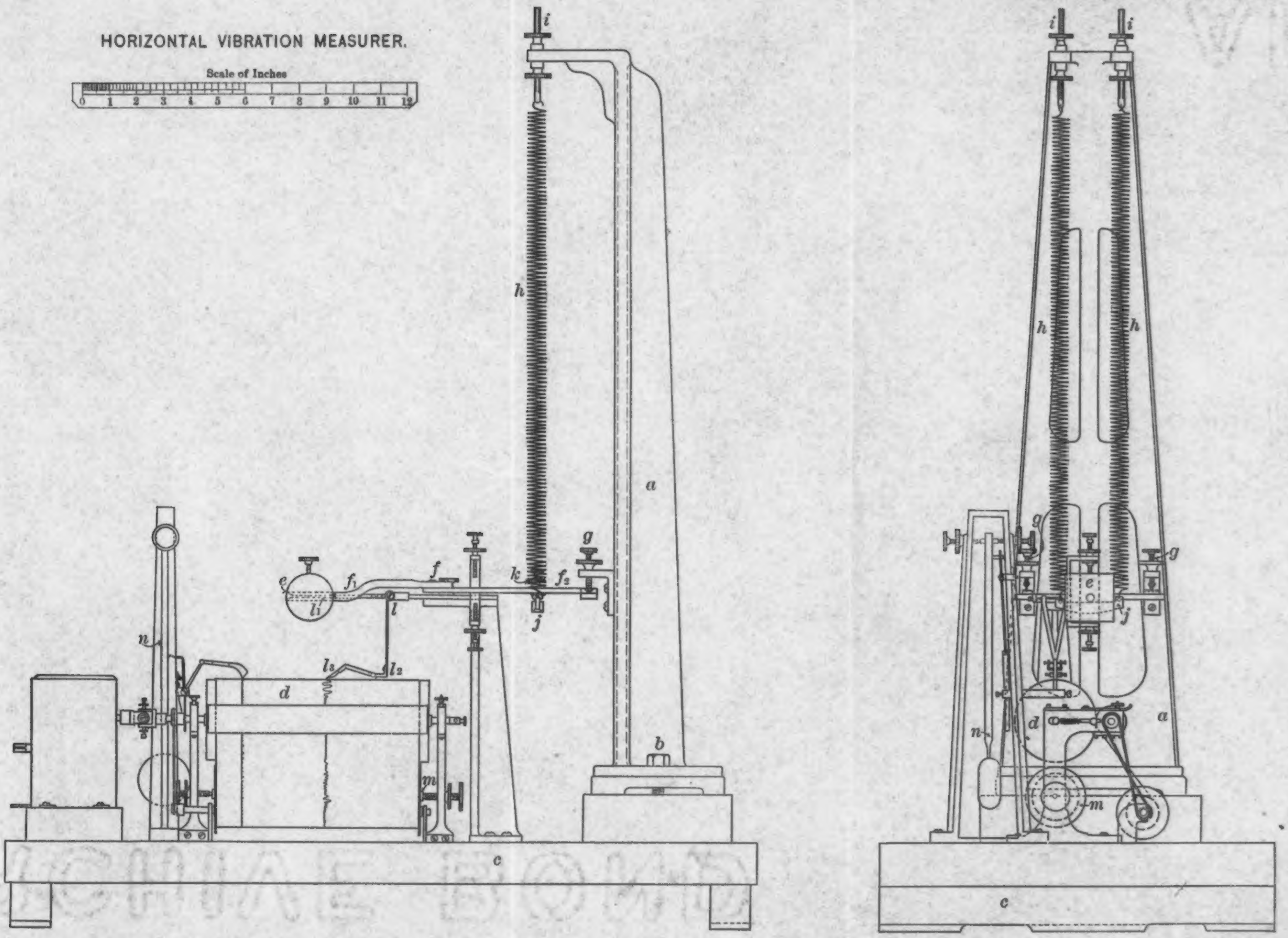
HORIZONTAL VIBRATION MEASURER.



around two cylinders, *d* and *m*; the rate of motion of the paper being accurately gauged by a time-marking pendulum, *n*, about 12 cm. in length, mechanically actuated. Each roll of paper lasts about 3 hours. The multiplication ratio of the pointer is $2\frac{1}{2}$ times.

Horizontal Vibration Measurer (Plate IV).—This is a single-component Ewing horizontal pendulum, which, to suit our purpose, is constructed with modifications, and strong enough to withstand the shakings under consideration.* The steady mass of the pendulum is a brass cylinder, *A*, filled with lead, about 2 kg. in weight; the distance betwen the center of the latter and the axis of rotation, determined by the line joining the points of suspension and of support, *B*, being 20 cm. The writing pointer magnifies the motion twice. The recording cylinder and the time-marking pendulum are exactly similar to those for the vertical component machine.

In each experiment on the destroyers, the instruments were firmly fixed to the floor of the cabin, on which they were set up, to prevent their being jerked by the strong vibrations of the steamers.

In the course of the experiments, Prof. Tanakadate's vertical-motion seismograph has also been used sometimes. When in use its record agreed closely with the record of the other vertical-motion instrument already described, so that, in the results given in the following pages, sometimes one record has been taken and sometimes the other, without discrimination.

Record of Revolutions.—In addition, a record of revolutions, both of port and starboard engines, was obtained. This was effected by the making and breaking of electric circuits by means of some reciprocating part of each engine; electro-magnets in the circuits actuated pens, and these, again, traced their record on continuous paper moved by clockwork around a revolving cylinder. A time scale, with breaks at $\frac{1}{2}$-sec. intervals, was simultaneously and similarly recorded, the making and breaking of circuit being, in this case, effected through the balance of a clock designed for the purpose.

To give identical times on the three paper records previously described, a pen on each was moved once every minute by a pneumatic push held in the hand of an observer.

* The instrument shown in Plate IV is slightly different from that used in the actual experiments.

1.50	245	239	....	....	......	......	....	248	I	.71	.92	....
1.51	241	248	....	....	......	......	....	239	I	.85	1.28	....
1.51½	240	247	....	....	......	......	....	235	I	.80	.80	Mixed with vibrations of Order IV, amplitude 0.16.
1.54¾	248	239	....	....	......	......	....	235	I	.80	1.28	....
1.55½	244	244	....	....	......	......	....	231	I	1.00	1.64	Vibrations very uniform, and no trace of superposition.
1.57	232	234	....	....	......	......	....	235	I	.80	.80	Mixed with very small quicker vibrations.
1.58	228	226	236	I	.40	.40	....	462	II	.32	.32	Followed by the vibrations of Order IV, amplitude 0.56.
1.59	220	205	218	I	.50	.50	....	400	II	.65	1.00	....
1.59⅝	197	202	....	....	......	......	....	403	II	.80	1.28	....
2.00	195	201	206	I	.50	.75	....	403	II	.60	1.16	Mixed with very small vibrations of Order IV.
2.01	196	199	200	I	.40	.70	....	400	II	.75	1.00	" " " "
2.03	198	201	....	....	......	......	....	400	II	.65	.96	" " " "
2.03½	198	200	....	....	......	......	....	392	II	.83	1.24	" " " "
2.05	168	190	....	....	......	......	....	561	II	.37	.55	Mixed with vibrations of Order IV, amplitude 0.2.
2.06	160	179	....	....	......	......	....	522	II	.20	.20	Mixed with smaller vibrations.
2.07	185	191	178	I	.50	.50	....	395	II	.24	.24	Mixed with vibrations of Order IV, amplitude 0.8.
2.08	204	206	217	I	.50	.50	....	392	II	.72	1.20	Superposed on the vibrations of Order I, of small amplitudes.
2.09	210	214	211	I	.30	.30	....	207	II	.65	.84	Mixed with vibrations of Order III, amplitude 0.2–0.44.
2.10	202	208	....	....	......	......	....	403	II	.45	.56	....
2.11	206	205	....	....	......	......	....	639	II	.32	.50	Superposed on small vibrations of Order I.
2.13	196	166	....	....	......	......	....	400	II	.64	.64	....
2.14	192	187	176	I	.60	.80	....	357	II	.48	.48	....
2.15	192	187	202	I	.40	.50	....	380	II	.44	.44	Mixed with small vibrations of Order VI.
2.16	194	187	200	I	.40	.50	....	375	II	.70	1.00	" " " "
2.17	198	195	211	I	.50	.50	....	400	II	.65	1.28	....
2.18	187	202	....	....	......	......	....	403	II	.80	.96	Superposed on small vibrations of slower order.
2.19	172	163	....	....	......	......	....	938	VI	.25	.30	" " " "
2.20	167	174	170	I	.38	.75	....	938	VI	.25	.32	" " " "
2.20½	177	179	183	I	.50	.50	....	483	III	.32	.32	....
2.21	177	183	....	....	......	......	....	1 080	VI	.27	.40	Mixed with vibrations of Order I, amplitude 0.4, and in the same place vibrations of Order III also occurring.
2.22	155	136	....	....	......	......	....	392	III	.35	.60	....
2.23	120	128	227	....	.50	.75	....	....	....	....	....	....
2.25	189	185	189	I	......	.80	....	442	II	.20	.20	....
2.26	192	184	196	I	.50	.75	....	1 180	VI	.20	.20	Superposed on small vibrations of Order II.
2.28	193	186	182	I	.70	.80	....	1 410	VI	.30	.40	....
2.29	190	185	189	I	.55	.55	....	372	II	.25	.36	Superposed on small vibrations of slower order.
2.30	181	181	170	I	.50	.60	....	536	III	.33	.50	" " " "
2.31	182	172	....	....	......	......	....	530	III	.20	.25	....
2.32	142	129	....	....	......	......	....	403	III	.20	.20	....
2.32½	137	113	....	....	......	......	....	403	III	.60	.60	....

Date of trial, March 20th, 1903.

TABLE 11.—TORPEDO-BOAT DESTROYER, *Harusame*.

Time of day.	Revolutions per minute. Starboard engine.	Revolutions per minute. Port engine.	Vibrations. Horizontal. Number of complete vibrations per minute (C_a).	Horizontal. Ratio $\frac{C_a}{\text{Rev.}}$ (C_b)	Horizontal. Average double amplitude, in millimeters.	Horizontal. Maximum double amplitude at about the same time, in millimeters.	Horizontal. Remarks.	Vertical. Number of complete vibrations per minute (C_d).	Vertical. Ratio $\frac{C_d}{\text{Rev.}}$ (C_e).	Vertical. Average double amplitude, in millimeters.	Vertical. Maximum double amplitude at about the same time, in millimeters.	Vertical. Remarks.
P. M.												
12.15½	119	125						250	II	.20	.32	These vibrations lasted only a short time.
12.22	120	127						240	II	.21	.28	Mixed with small vibrations of Order IV.
12.23	125	129						248	II	.25	.40	" " " "
12.24	126	131						256	II	.25	.40	" " " "
27	124	130						250	II	.29	.48	Mixed with vibrations of Order III, amplitude 0.28.
12.28	126	134						392	III	.21	.32	Mixed with vibrations of higher order.
12.31	123	149						400	III	.22	.28	
12.33	139	150						417	III	.12	.12	
12.41	146	156	155	I	.50	.50		469	III	.16	.16	
12.44½	130	149	186		.50	.75		392	III	.26	.44	
12.44	121	138	211		.20	.40		403	III	.30	.40	
12.45½	120	138	200		.50	.50		403	III	.34	.48	Mixed with vibrations of higher order.
12.59	163	162	158	I	.25	.25	Mixed with vibrations of higher order.	703		.06		
1.00	172	173	172	I	.50	.50		1 050	VI	.13	.20	
1.01	159	176						522	III	.13	.20	
1.04	172	177	179	I	.40	.60	Mixed with very small vibration of Order III.	548	III	.10	.15	
1.12	172	180	179	I	.50	1.20		530	III	.06	.20	
1.17	182	129						382	III	.44	.48	
1.25	134	125						403	III	.46	.72	
1.27	130	125						417	III	.26	.48	
1.28½	142	145	142	I	.70	.70		436	III	.08	.24	
1.33	152	157	159	I	.45	.45						
1.34	152	154	162	I	.25	.40						
1.47	191	199						392	II	.80	.80	Mixed with small vibrations of Order VI.
1.48	191	200						403	II	.50	.80	
1.49	199	201						405	II	.52	.84	
1.49¼	215	214						652	III	.76	.76	Superposed on the vibrations of Order I, amplitude 0.80, very distinctly.
1.49¾	228	228						221	I	.72	.72	Superposed on the vibrations of Order III, amplitude 0.56.

Analysis of Records.—To count the number of vibrations occurring in one minute, a limited number of such vibrations (perhaps 20) were measured off on the diagram; the time occupied by these was taken by the time scale; thence, by a simple proportion, the number per minute was deduced. To get the number of revolutions per minute, a somewhat different course suited the record better: a definite interval (perhaps 6 sec.) was measured on the time scale, and the number of revolutions (in units and decimals) occurring during this interval was counted from the revolution record; again, a simple proportion gave the number per minute. Columns C_b and C_e, in Tables 11, 16 and 17, show the relation between vibrations and revolutions, Number I* representing agreement, and Number II representing vibrations $= 2 \times$ revolutions, and so on.

From the above description of the method of counting vibrations and revolutions, it will be seen readily that the tabulated amounts can only be approximate; in the relation, therefore, noted in Columns C_b and C_e (see Tables 11, 16 and 17) an exact agreement or exact multiple is assumed, even when the record shows a departure from exact coincidence.

Results.—The results obtained from the diagrams are for the *Harusame*, in Table 11, and for the *Hayatori*, in Tables 16 and 17. In these tables the 1st column gives the time of day, the 2d and 3d columns, the revolutions of starboard and port engines, respectively, and the remaining columns, the horizontal and vertical vibrations, in number per minute and in double amplitude, together with the ratio already mentioned. The small amplitude of vibration, both vertical and horizontal, is remarkable; it never exceeded 1.04 mm., this amount occurring once as the maximum double amplitude of vertical vibrations of the 1st order in the *Harusame*. In this connection, it is a little to be regretted that it was not possible to obtain experiments at revolutions higher than 245 for the *Harusame* and 342 for the *Hayatori* (*viz.*, 340 for the starboard engine, and 344 for the port engine), while the revolutions corresponding to the highest speed on one trial were 370 for the *Harusame* and 383 for the *Hayatori*.

Intensity of Motion.—In other tables, to be referred to presently,

* It has been usual to call these vibrations of 1st period, 2d period, etc. The writers prefer to follow German nomenclature and speak of 1st order or Order I, 2d order or Order II, etc.

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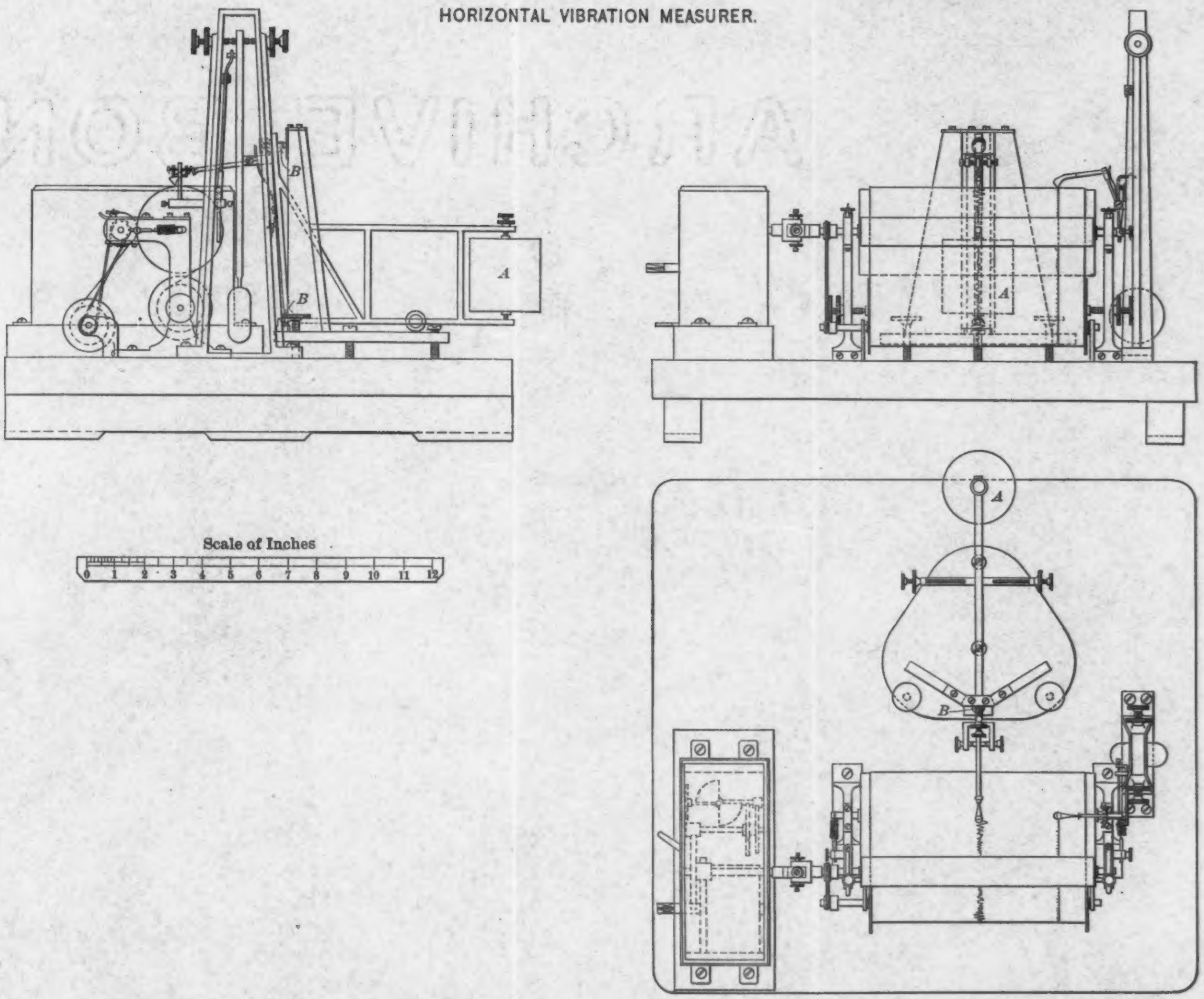
HORIZONTAL VIBRATION MEASURER.



the acceleration value, $\frac{4\pi^2 a}{P^2}$, is given, where 2a is the double amplitude, and P the complete period of vibration.

This value $\left(\frac{4\pi^2 a}{P^2}\right)$ may be taken to represent intensity of motion of single vibrations. In the case of purely harmonic motion, it simply gives the well-known expression for maximum acceleration; and for motion varying as in the experiments here investigated it may be taken to express maximum acceleration in a fairly approximate way. In order to compare this maximum acceleration with gravity, it should be remembered that $g = 9\,800$ mm. (per sec.)^2.

Published Records.—Previously published records of vibrations of steamers are principally German, instruments devised by Herr Otto Schlick having been used in most of the experiments noted.*

TORPEDO-BOAT DESTROYER, *Harusame.*

The experiments upon this vessel were made March 20th, 1903, with the measuring instruments set up in the wardroom.

Revolutions.—The starboard and port engines seldom ran at exactly the same number of revolutions, thus, Table 11 shows differences varying from 0 to 30 per minute. In the majority of cases, indeed, in nearly two-thirds of those recorded, the differences lay between 0 and 7 per minute. The mean revolutions of the two engines varied between 122 and 245.

Vertical Vibrations.

Relative Frequency of the Different Orders of Vibrations.—The vertical motion generally consisted of vibrations of one order with smaller vibrations of another order superposed. Confining our attention to the predominating vibrations at the various times, the number of occurrences of the different orders of vibrations, as shown by Table 11, are as follows:

Order	I	8	cases,
"	II	26	"
"	III	24	"
"	IV	0	"
"	V	0	"
"	VI	6	"

* A list of these publications and of papers dealing with the subject will be found in *Engineering* (London) for 2d Jan., 1903, in connection with a series of articles communicated to that periodical by Rear-Admiral Melville.

Thus, the vibrations of the 2d and 3d orders occurred most frequently, and those of the 1st and 6th orders only rarely; vibrations of the 4th and 5th orders were absent as principal vibrations, although those of the 4th order occurred in a few cases as small superpositions only. It must be noted that traces of Order I were always present, more or less, even when the vibrations of other orders greatly predominated.

Revolutions and the Different Orders of Vibrations.—The limits of revolutions (mean of starboard and port engines) between which the different orders of vibrations occurred prominently, were as follows:

Order I....212 to 245 revolutions (the highest recorded),
" II....122 (lowest recorded) to 227,
" III....125 to 215,
" VI....168 to 190.

Thus, vibrations of Orders II and III occurred through a wide range of revolutions, while the predominance of those of Order I was confined to a narrow range at comparatively high revolutions, *viz.*, between 212 and 245. Sixth order vibrations also occurred only within narrow limits; 4th order vibrations occurred as auxiliary movements only, between revolutions 179 and 227.

Mean Amplitude.—The mean average double amplitude and the mean maximum double amplitude, arranged in ascending revolutions, are given in Table 12; the intensity of motion, as defined on pages 96 and 97, in Table 13. The amplitudes exhibited in Table 12 are means of groups of several readings in Table 11, in which the revolutions did not differ largely.

Mean Average Vibrations.—From Tables 12 and 13 it will be seen that, within the limits of the experiments, the greatest mean average, 2a, of 1st order vibrations was 0.79 mm., while the greatest of the 2d, 3d and 6th orders were 0.65, 0.54 and 0.26 mm., respectively. The intensity, or maximum acceleration was, however, smallest for the 1st order, and increased successively for the 2d, 3d and 6th orders; the greatest intensities of motion for these four orders being, respectively, 231, 540, 1 240 and 2 130 mm. (per sec.)^2 or roughly in the ratios 1 : 2.3 : 5.4 : 9.2.

TABLE 12.—*Harusame.* VERTICAL VIBRATIONS. MEAN AVERAGE AND MEAN MAXIMUM DOUBLE AMPLITUDES (2a).

Revolutions (mean of starboard & port engines)	ORDER I.		ORDER II.		ORDER III.		ORDER VI.	
	Average. (1)	Maximum. (2)	Average. (3)	Maximum. (4)	Average. (5)	Maximum. (6)	Average. (7)	Maximum. (8)
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
126	....	....	0.24	0.38	....	....	....	....
129	....	....	....	....	0.37	0.50	....	....
142	....	....	....	....	0.20	0.29	....	....
171	....	....	....	....	....	....	0.21	0.27
176	....	....	....	....	0.21	0.30	....	....
186	....	....	0.33	0.36	....	....	0.26	0.33
195	....	....	0.66	0.92	....	....	....	....
207	....	....	0.59	0.88	....	....	....	....
211	....	....	....	....	0.54	0.63	....	....
236	0.79	1.04	....	....	....	....	....	....

TABLE 13.—*Harusame.* VERTICAL VIBRATIONS. MAXIMUM ACCELERATION CORRESPONDING TO FIGURES IN TABLE 12.

Revolutions.	ORDER I.		ORDER II.		ORDER III.		ORDER VI.	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	$\frac{\text{mm.}}{\text{sec.}^2}$	$\frac{\text{mm.}}{\text{sec.}^2}$	$\frac{\text{mm.}}{\text{sec.}^2}$	$\frac{\text{mm.}}{\text{sec.}^2}$	$\frac{\text{mm.}}{\text{sec.}^2}$	$\frac{\text{mm.}}{\text{sec.}^2}$	$\frac{\text{mm.}}{\text{sec.}^2}$	$\frac{\text{mm.}}{\text{sec.}^2}$
126	....	....	81	129	....	....	....	....
129	....	....	....	....	324	438	....	....
142	....	....	....	....	177	256	....	....
171	....	....	....	....	....	....	1 090	1 410
176	....	....	....	....	322	460	....	....
186	....	....	291	317	....	....	2 130	2 710
195	....	....	551	770	....	....	....	....
207	....	....	540	807	....	....	....	....
211	....	....	....	....	1 240	1 440	....	....
236	231	304	....	....	....	....	....	....

Mean Maximum Vibrations.—Figures similarly obtained from mean maximum vibrations are 1.04, 0.92, 0.63 and 0.33, for the four orders, respectively, giving accelerations of 304, 807, 1 440 and 2 710 mm. (per sec.)^2. These last have the ratios of 1 : 2.6 : 4.7 : 8.9.

Absolutely Greatest Vibrations.—The absolutely greatest movements and the corresponding maximum accelerations of the different orders were as in Table 14.

TABLE 14.—*Harusame.* VERTICAL VIBRATIONS. ABSOLUTELY GREATEST MOVEMENTS ($2a_0$).

Order.	Revolutions.	Vibrations per minute.	$2a_0$ mm.	Maximum acceleration $\frac{mm.}{sec.^2}$
I............	244	231	1.64	480
II............	200	403	1.28	890
III............	215	652	0.76	1 770
VI............	190	1 410	0.40	4 360

From Table 14 it will be seen that the absolutely greatest vibrations all occurred between revolutions 190 and 244; their $2a_0$ bore the ratios 4.1 : 3.2 : 1.9 : 1, the corresponding accelerations having the ratios 1 : 1.9 : 3.7 : 9.1.

Horizontal Vibrations.

The horizontal motion consisted especially of vibrations of the 1st order, there being, among the 30 cases contained in Table 11, only four in which the vibrations belonged approximately to the 2d order. In some cases there were also superpositions of small movements of the 3d order. In Table 15, aranged in ascending revolutions, is given the mean average double amplitude of the 1st order. These means are taken from groups of several readings in Table 11, in which the revolutions did not differ largely.

TABLE 15.—*Harusame.* HORIZONTAL VIBRATIONS. MEAN AVERAGE, AND MEAN MAXIMUM DOUBLE AMPLITUDE (2a) OF ORDER I.

Revolutions (mean of starboard & port engines).	Vibrations per minute.	AVERAGE VIBRATIONS.		MAXIMUM VIBRATIONS.	
		2a mm.	Maximum acceleration $\frac{mm.}{sec.^2}$	2a mm.	Maximum acceleration $\frac{mm.}{sec.^2}$
153............	155	0.43	57	0.46	61
176............	176	0.46	78	0.69	117
189............	189	0.52	102	0.65	127
198............	206	0.47	109	0.65	151
214............	221	0.43	115	0.43	115

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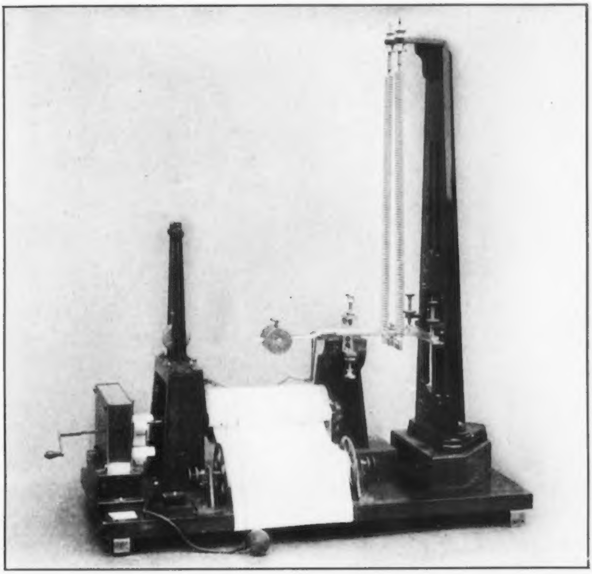

FIG. 1.—VERTICAL VIBRATION MEASURER.

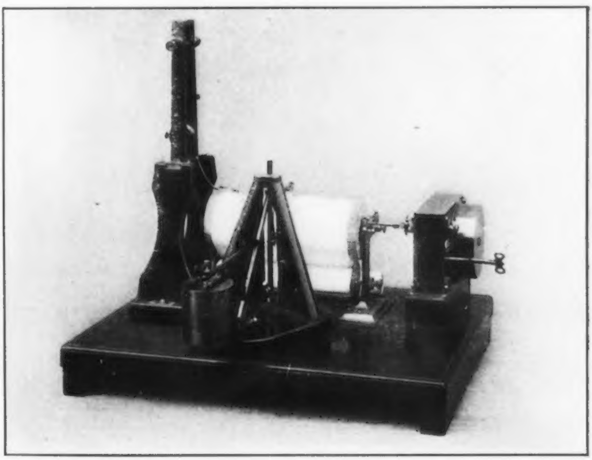

FIG. 2.—HORIZONTAL VIBRATION MEASURER.

Mean Average and Mean Maximum Vibrations of Order I.—From Table 15 it will be seen that the amplitude of the mean average vibrations remained nearly constant, consequently, the corresponding maximum acceleration increased with the revolutions. Maximum vibrations exceeded average vibrations from 0 to 30 per cent.

$2a_0$ *of 1st Order.*—The absolutely greatest vibration ($2a_0$) was 1.2 mm., and occurred with revolution 176.

Vibrations of Orders II and III.—The four cases in which vibrations were approximately of the 2d order occurred between revolutions 124 and 140. Those of the 3d order, as already mentioned, occurred only as small superpositions upon vibrations of the 1st order; their absolute maximum was 0.2 mm., with corresponding revolutions 173 to 175, and maximum acceleration, 287 mm. (per sec.)^2.

Corresponding Horizontal and Vertical Vibrations.—In the only case of principal vertical vibrations of Order I, at revolutions lower than 226 (*viz.*, at 212 revolutions), the average double amplitude was 0.65 mm., the maximum, 0.84; the mean of 5 cases of horizontal vibrations gave revolutions, 214, average and maximum $2a = 0.43$. Thus, horizontal vibration was considerably less than vertical. The absolutely greatest vibrations were 1.2 mm. for horizontal against 1.64 mm. for vertical motion; but here the revolutions were very different. The absolutely greatest acceleration was 212 mm. (per sec.)^2 for 1st order horizontal vibrations, and 287 for 3d order. These numbers may be compared with those in Table 14, when the smallness of horizontal movement, especially in relation to the vertical movement of the higher orders, will be apparent at once.

TORPEDO-BOAT DESTROYER, *Hayatori.*

The experiments upon this vessel were made June 4th and 11th, 1903, with the measuring instruments in the wardroom; the position of the instruments was the same as on the *Harusame.*

Revolutions.—The mean revolutions of the two engines varied between 200 and 301 on the first day, and 156 and 342 on the second. The differences of revolutions of starboard and port engines were somewhat less than on the *Harusame,* varying from 0 to 23 per min. on the first day, and from 0 to 29 per min. on the second.

0.29	256	257	258	I	.30	.50	....	508	II	.36	.40	Both before and after this time vibrations of Order I occurring.
0.31	257	255	......	......	......	......	Vibrations were very slight.	255	I	.50	.50	Mixed with vibrations of Order II, amplitude 0.24.
0.32	257	254	254	I	.35	.60	....	511	II	.32	.48	A little earlier than this time, vibrations of Order I predominated, mixed with vibrations of Period II.
0.36	247	255	......	......	......	......		249	I	.50	.80	Also quicker vibrations occurring.
0.37	256	252	261	I	.20	.75	....	258	I	.40	.40	Mixed with vibrations of Order II, amplitude 0.1.
0.39	252	257	268	I	.20	.60	....	251	I	.40	.64	" and amplitude 0.02.
0.40½	250	257	247	I	.20	.75	....	258	I	.56	.56	Mixed with vibrations of Order II.
0.41	253	254	258	I	.35	.75	....	512	I	.20	.40	....
0.42	256	256	247	I	.20	.50	Mixed with small vibrations of Order (?).	215	I	.40	.52	Mixed with small vibrations of Order II.
0.44	255	258	......	......	......	......		245	I	.40	.80	" " " "
0.54	258	257	261	I	.35	.70	Mixed with very small vibrations of Order III.	......	......	......	......	....
0.56	254	256	250	I	.20	.90	Mixed with very small quicker vibrations.	511	II	.23	.48	....
0.57½	257	256	240	I	.30	.83	....	261	I	.56	.68	Mixed with smaller vibrations.
0.58½	257	259	246	I	.30	.75	Mixed with very small quicker vibrations.	257	I	.32	.56	Mixed with vibrations of Order II, amplitude .16.
1.00	257	253	249	I	.75	.80	" " " "	494	II	.36	.60	Mixed with small vibrations of Order I.
1.02	255	256	250	I	.50	.80	" Order III.	525	II	.28	.64	" " " "
1.04	257	254	260	I	.60	.70	" "	253	I	.60	.68	Mixed with vibrations of Order II.
1.05	234	257	770	III	.35	.70	....	238	I	.80	1.20	....
1.10	244	257	......	......	......	......	....	900 about.	?	.28	.28	These vibrations were very active; very small slower vibrations also existing.
1.11	290	287	293	I	.50	.80	....	895 about.	III	.24	.24	Mixed with small quicker vibrations.
1.12½	294	295	301	I	.70	.90	....	900 about.	III	.24	.24	" " " "
1.14	296	305	293	I	.70	.80	....	895	III	.20	.20	" " " "
1.18	297	297	293	I	.55	.80	....	895	III	.20	.20	" " " "
1.20	247	265	243	I	.55	.70	....	250	I	.56	.86	....
1.23	242	238	236	I	.50	.80	....	238	I	.56	.72	Mixed with very small quicker vibrations.
1.23⅔	241	236	248	I	.60	.75	....	236	I	.72	.72	....
1.26	236	233	227	I	.20	.60	....	238	I	.40	.60	Mixed with very small quicker vibrations.
1.27	233	240	240	I	.70	.85	....	238	I	.40	.40	....
1.28⅛	238	242	226	I	.30	.60	....	243	I	.84	.96	....
1.29½	246	242	242	I	.40	.60	....	239	I	.65	.72	....
1.30	245	240	251	I	.40	.45	....	250	I	.60	.68	....

Date of trials, June 4th, 1903.

TABLE 16.—TORPEDO-BOAT DESTROYER, *Hayatori*.

Time of day.	Revolutions per Minute.		Vibrations. Horizontal.					Vibrations. Vertical.				
	Starboard engine.	Port engine.	Number of complete vibrations per minute (C_a).	Ratio $\frac{C_a}{\text{Rev.}}$ (C_b)	Average double amplitude, in millimeters.	Maximum double amplitude at about the same time, in millimeters.	Remarks.	Number of complete vibrations per minute (C_d).	Ratio $\frac{C_d}{\text{Rev.}}$ C_e	Average double amplitude, in millimeters.	Maximum double amplitude, time, in millimeters.	Remarks.
A. M. 10.19	199	200	196	I	.35	.40	....	400	II	.30	.64	....
10.23	194	209	204	I	.30	.30	....	390	II	.50	.64	....
10.25	207	207	210	I	.50	.50	....	398	II	.44	.56	....
11.50	247	248	....	....	....	....	....	245	I	.48	.60	....
11.51	244	248	....	....	....	....	....	239	I	.40	.80	....
11.53	215	236	....	....	....	....	....	243	I	.60	.72	Mixed with small vibrations of Order III.
11.58	238	242	252	I	.25	.30	....	231	I	.70	1.00	....
11.59	248	245	246	I	.25	.30	Mixed with small vibrations of Order II.	243	I	.60	.64	....
P. M. 0.01½	246	247	503	II	.15	.25	Followed by the vibrations 246, amplitude 0.25.	239	I	.40	.96	Mixed with small vibrations of Order III.
0.05	242	249	252	I	.80	.80	Followed by the vibrations 638, amplitude 0.2.	243	I	.48	....	Mixed with small vibrations of Order III.
0.06	244	241	243	I	.30	.50	....	238	I	.60	1.00	....
0.07	244	243	252	I	.65	.65	....	244	I	.28	....	....
0.24	247	251	....	....	....	....	....	250	I	1.00	1.16	Both before and after this time, vibrations of Order II and amplitude 0.2 occurring.
0.26	249	253	250	I	.20	.70	....	247	I	.60	1.16	" "
0.27	253	248	....	....	....	....	....	251	I	.52	.68	Slightly mixed with vibrations of Order II, and after this time vibrations of Order II and amplitude 0.32 occurring.
0.28	254	255	266	I	.30	.65	....	253	I	.40	.40	Mixed with vibrations of Order II, amplitude 0.16.

10.35	240	224	241	I	.50	.50	Mixed with very small vibrations of Order III (?), amplitude 0.2.	240	I	.60	.60	Also very small vibrations of Order III.
10.36	271	258	254	I	.40	.75	Mixed with very small vibrations of Order III.	270	I	.60	.60	" " " "
10.37	282	288	283	I	.30	.30	....	860	III	.30	.56	Also vibrations of Order I and amplitude 0.3.
10.38	285	289	283	I	.40	.60	Mixed with very small vibrations of Order III or IV.	890	III	.40	.61	....
10.39	289	296	295	I	.40	.75	" " " "	890	III	.40	.48	....
10.40	306	294	304	I	.30	.50	" " " "	304	I	.24	.48	Mixed with small vibrations of Order II or III.
10.41	319	318	....	....	....	....	....	323	I	.60	.60	" " " "
10.43	324	330	311	I	.40	.90	....	327	I	.55	.55	Mixed with small vibrations of Order III, amplitude 0.1.
10.43½	333	335	340	I	.35	.80	....	680	II	.65	.85	Mixed with small vibrations of Order VI or VIII.
10.45	337	540	340	I	.60	.91	....	333	I	.80	.90	Mixed with vibrations of Order II, amplitude 0.4, also with vibrations of Order IV.
10.46½	340	344	348	I	.40	.90	....	684	II	.65	.88	Mixed with very small vibrations of Order VIII.
10.49	340	343	357	I	.30	.80	....	632	II	.40	.65	Mixed with small vibrations of Order VI or VIII.
10.50	340	341	348	I	.30	.80	....	636	II	.65	1.00	" " " "
10.51	330	327	328	I	.70	.70	Mixed with very small vibrations of Order III.	......	I	.80	.90	Mixed with vibrations of Order II, also with vibrations of Order VI or VIII.
10.52	332	337	346	I	.30	.50	....	....	....	....	....	....
10.53	330	330	343	I	.20	.40	....	682	II	.40	.80	Mixed with very small vibrations of Order VIII.
10.54	330	339	347	I	.40	.50	....	664	II	.60	.75	Mixed with very small vibrations of Order VIII, and amplitude about 0.15.
10.55	324	328	326	I	.40	.70	....	665	II	.60	.75	Mixed with vibrations of higher orders.
10.58	310	293	1 200	IV	.20	.50	....	....	....	....	....	....
10.59	276	260	273	I	.20	.50	....	274	I	.45	.80	Mixed with very small vibrations of Order II.
P. M. 12.23	202	198	200	I	.75	.80	....	408	II	.60	.80	....
12.24	190	161	600	....	.20	.40	....	800	?	.25	.25	....
12.24½	186	159	....	....	....	....	....	570 to 650	?	.30	.30	....
12.26	178	182	186	I	.50	1.20	Mixed with very small vibrations of Order III.	715	IV	.30	.30	....
12.27	162	172	500	III	.40	.70	....	550 to 930	?	.20	.24	....
12.28	160	172	....	....	....	....	....	850	V	.15	.15	....
12.30	199	192	....	....	....	....	....	398	II	.40	.70	....
12.31	150	162	....	....	....	....	....	572	?	.20	.20	....
12.32	162	163	....	....	....	....	....	637	IV	.25	.25	....

Date of trials, June 11th, 1903.

TABLE 17.—TORPEDO-BOAT DESTROYER, *Hayatori*.

Time of day.	Revolutions per minute. Starboard engine.	Revolutions per minute. Port engine.	Horizontal. Number of complete vibrations per minute (C_a).	Horizontal. Ratio $\frac{C_a}{\text{Rev.}}$ (C_b)	Horizontal. Average double amplitude, in millimeters.	Horizontal. Maximum double amplitude at about the same time, in millimeters.	Horizontal. Remarks.	Vertical. Number of complete vibrations per minute (C_d).	Vertical. Ratio $\frac{C_d}{\text{Rev.}}$ (C_e)	Vertical. Average double amplitude, in millimeters.	Vertical. Maximum double amplitude at about the same time, in millimeters.	Vertical. Remarks.
A. M.												
9.57	197	192	200	I	.40	.60		388	II	.48	.72	
9.58	198	190	194	I	.20	.40		397	II	.55	.55	
9.59	198	192	202	I	.40	.60		397	II	.48	.70	
10.00	198	195	206	I	.20	.50		390	II	.48	.72	
10.01	192	186	206	I	.20	.40		400	II	.55	.72	
10.02	200	193	201	I	.30	.50		375	II	.60	.72	
10.03	197	190	192	I	.40	.50		395	II	.55	.50	
10.04	197	195	198	I		.44		370	II	.60	.80	
10.05	201	193	196	I	.20	.50		390	II	.60	.60	
10.06	198	?	198	I	.30	.50		398	II	.55	.80	
10.09	192	172	400	II	.25	.40		397	II	.30	.40	Also very small vibrations not easily measured.
10.08	199	199	197	I	.50	.60		385	II	.35	.50	
10.09	200	193	200	I	.50	.55		397	II	.50	.60	
10.10	198	?	206	I	.55	.55		392	II	.60	.80	
10.11	202	195	207	I	.70	.70		410	II	.50	.70	
10.12	205	196	195	I	.50	.50		430	II	.45	.45	
10.13	205	199	208	I	.50	.50		430	II	.35	.60	
10.26	247	249	257	I	.25	.30	Mixed with small vibrations of Order III or IV.	238	I	.80	.40	Also very small vibrations not easily measured.
10.27	251	250	253	I	.40	.40		247	I	.60	.72	" " " "
10.28	236	254	236	I	.30	.50		237	I	.60	.60	Also small vibrations of Order III.
10.29	247	247	239	I	.35	.35	Mixed with small vibrations of Order III.	243	I	1.00	1.00	Also small vibrations not easily measured.
10.30	232	243	235	I	.50	.50		238	I	1.00	1.60	" " " "
10.31	243	243	238	I	.50	.70		242	I	.65	.88	" " " "
10.32	244	244	245	I	.50	.50		242	I	.95	.95	" " " "
10.33	255	248	253	I	.55	.55	Mixed with very small vibrations.	250	I	1.00	1.00	" " " "
10.34	254	250	256	I	.70	.90		255	I	.80	.84	" " " "

Vertical Vibrations.

Relative Frequency of the Different Orders of Vibrations.—According to Tables 16 and 17 the relative frequency of the principal vibrations of the different orders was as follows:

Order I	49	cases
" II	35	"
" III	8	"
" IV	2	"
" V	1 (?)	case
" VI	0	"

Thus, the vibrations of the 1st order occurred most frequently, then those of the 2d order; there were a few only of the 3d order, two of the 4th order, and none of the 6th. Vibrations of Order V occurred, or appeared to occur, in one case; the isolation of this one case, perhaps, helps to mark more emphatically the absence of vibrations of this order.

Revolutions and the Different Orders of Vibrations.—The limits of revolutions (mean of starboard and port engines) between which the different orders of vibrations occurred prominently were as follows:

Order I....226 to 339 (almost the highest recorded),
" II....182 to 342 (highest recorded),
" III....251 to 301,
" IV....163 to 180.

Vibrations of the 1st order occurred between 226 and 271 revolutions and then again between 300 and 339. Those of the 2d order had the greatest total range; they occurred between 182 and 257 revolutions, and again between 326 and 342 revolutions (the highest recorded).

Occasionally 1st order and 2d order vibrations alternated somewhat regularly; this is especially to be seen between 12.32 and 1.02 P. M. on June 4th, 2d order vibrations then being often nearly equal to 1st order, as shown in Table 18.

In the 8 cases given in Table 18, with all revolutions between 254 and 257, the average double amplitude for 1st and 2d orders was, respectively, 0.55 and 0.35 mm., related as 1.6:1.

TABLE 18.—*Hayatori.* ALTERNATION OF 1ST AND 2D ORDER VIBRATIONS.

Approximate time.	Revolutions (mean of starboard & port engines).	ORDER I VIBRATIONS.		ORDER II VIBRATIONS.	
		2a mm.	Vibrations per minute.	2a mm.	Vibrations per minute.
12.32 P. M.	255	0.48	257	0.40	511
12.37 "	254	0.40	258	0.32	522
12.39 "	254	0.64	251	0.32	514
12.55 "	257	0.48	257	0.32	505
12.56 "	255	0.48	257	0.40	511
12.57½ "	256	0.68	261	0.32	505
1.00 "	255	0.60	252	0.32	505
1.02 "	256	0.64	271	0.36	494

Mean Amplitudes.—The mean average double amplitude and the mean maximum double amplitude are given in Table 19; the corresponding intensity of motion, in Table 20. The amplitudes of Table 19 are means of groups of several readings in Tables 16 and 17, for which differences of revolutions were not great.

TABLE 19.—*Hayatori.* VERTICAL VIBRATIONS. MEAN AVERAGE AND MEAN MAXIMUM DOUBLE AMPLITUDES (2a).

Revolutions (mean of starboard & port engines).	ORDER I.		ORDER II.		ORDER III.		ORDER IV.	
	Average. (1)	Maximum. (2)	Average. (3)	Maximum. (4)	Average. (5)	Maximum. (6)	Average. (7)	Maximum. (8)
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
172							0.28	0.28
193			0.49	0.64				
198			0.51	0.66				
203			0.41	0.61				
242	0.64	0.87						
255	0.48	0.66						
256			0.29	0.50				
258	0.69	0.79						
287					0.28	0.33		
323	0.60	0.69						
336			0.56	0.81				

Mean Average Vibrations.—From Tables 19 and 20 it will be seen that, within the limits of the experiments, the greatest 2a of vibrations of the 1st, 2d, 3d and 4th orders (taking the mean of the average vibrations) was 0.69, 0.56, 0.28 and 0.28 mm., respectively. The greatest intensity, or maximum acceleration, showed 340, 1 380, 1 180 and 702 mm. (per sec.)^2, in which the ratios are 1 : 4.3 : 3.5 : 2.1.

TABLE 20.—*Hayatori*. VERTICAL VIBRATIONS. MAXIMUM ACCELERATION CORRESPONDING TO THE FIGURES OF TABLE 19.

Revolutions.	ORDER I.		ORDER II.		ORDER III.		ORDER IV.	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	$\frac{\text{mm.}}{\text{sec.}^2}$		$\frac{\text{mm.}}{\text{sec.}^2}$		$\frac{\text{mm.}}{\text{sec.}^2}$		$\frac{\text{mm.}}{\text{sec.}^2}$	
172	......	......	......	......	......	......	702	702
193	......	......	415	541	......	......	......	......
198	......	......	447	579	......	......	......	......
203	......	......	352	524	......	......	......	......
242	200	276	......	......	......	......	......	......
255	164	226	......	......	......	......	......	......
256	......	......	412	711	......	......	......	......
258	254	291	......	......	......	......	......	......
287	......	......	......	......	1 180	1 396	......	......
323	340	391	......	......	......	......	......	......
336	......	......	1 380	1 970	......	......	......	......

Mean Maximum Vibrations.—The mean maximum vibrations of the same four orders (as seen from the same Tables, 19 and 20) had for their greatest values 0.87, 0.81, 0.33 and 0. 28 mm., respectively, with corresponding intensities of 276, 1 970, 1 396 and 702 mm. (per sec.)^2. These last-mentioned figures have the mutual ratios of 1.0 : 7.9 : 5.1 : 2.5.

Absolutely Greatest Vibrations.—The absolutely greatest movements and the corresponding maximum acceleration of the different orders were as in Table 21.

From Table 21 it will be seen that the absolutely greatest vibrations of the 1st, 2d, 3d and 4th orders bore the ratios 5.3 : 3.3 : 1.9

: 1, while their intensities bore the ratios 1 : 4.5 : 4.6 : 1.7, respectively.

TABLE 21.—*Hayatori.* VERTICAL VIBRATIONS. ABSOLUTELY GREATEST MOVEMENT ($2a_0$).

Order.	Revolutions.	Vibrations per minute.	$2a_0$ mm.	Maximum acceleration $\frac{mm.}{(sec.)^2}$
I	238	238	1.60	495
II	341	636	1.00	2 210
III	285	860	0.56	2 270
IV	180	715	0.30	840

Horizontal Vibrations.

The horizontal motion consisted essentially of vibrations of the 1st order, there being, among the 87 cases contained in Tables 16 and 17, only one case of the 4th order and two cases each of the 2d and 3d orders. In Table 22, arranged in ascending revolutions, is given the mean average 2a of Order I. These means are taken from groups of several readings in Tables 16 and 17, in which the difference of revolutions was not great.

TABLE 22.—*Hayatori.* HORIZONTAL VIBRATIONS. MEAN AVERAGE AND MEAN MAXIMUM DOUBLE AMPLITUDE (2a) OF ORDER I.

Revolutions (mean of starboard & port engines).	Vibrations per minute.	AVERAGE VIBRATIONS.		MAXIMUM VIBRATIONS.	
		2a mm.	Maximum acceleration. $\frac{mm.}{(sec.)^2}$	2a mm.	Maximum acceleration. $\frac{mm.}{(sec.)^2}$
196	200	0.42	92	0.50	125
203	203	0.38	86	0.40	90
243	244	0.45	148	0.56	183
255	253	0.34	119	0.70	246
284	282	0.33	144	0.57	248
296	295	0.61	290	0.83	395
335	339	0.40	252	0.72	454

Vibrations of 1st Order.—From Table 22 it will be seen that the amplitude of vibration did not vary greatly. With the exception of the vibration corresponding to revolutions 296, indeed, the variation was exceedingly small. The absolutely greatest motion amounted to 1.2 mm. of double amplitude; this occurred at revolutions 180. The absolutely greatest intensity was 574 mm. (per sec.)^2, occurring at 342 revolutions, with a corresponding double amplitude of 0.90 mm.

Vibrations of 2d Order.—As principal vibrations, these occurred only twice, *viz.*, at revolutions 182 and 247. As superpositions, they occurred principally between revolutions 250 and 256. The greatest had a double amplitude of 0.25 mm. with a corresponding maximum acceleration of 348 mm. (per sec.)^2.

Vibrations of 3d Order.—These also, as principal vibrations, occured only twice, *viz.*, at revolutions 167 and 246. As superpositions they occurred principally between revolutions 247 and 329. The greatest double amplitude was 0.25 mm. and the maximum acceleration 790 mm. (per sec.)^2.

Vibrations of 4th Order.—These occurred only once with revolutions 302.

Comparison of Horizontal and Vertical Vibrations.—The horizontal vibrations of the 1st order were, in general, slightly less than the vertical vibrations of the same order; indeed, a general average, taken from Tables 22 and 20, respectively, shows a ratio of 0.7 : 1.0 between the two. The greatest intensity occurred, for both directions of motion, with vibrations of the 3d order; it was 790 mm. (per sec.)^2 for horizontal and 2 270 for vertical, giving a ratio of 0.35 : 1.0.

Comparison of the Vertical Vibrations of the *Harusame* and the *Hayatori*.

Comparative Amplitudes.—From Tables 14 and 21 it appears that the absolutely greatest vibration ($2a_0$) of the two vessels was approximately identical, that of the *Harusame* being, if anything, slightly greater than that of the *Hayatori*, in all the orders. The

greatest $2a_0$ in any order was in the 1st, amounting to 1.64 mm. (revolutions = 244) for the *Harusame* and 1.60 mm. (revolutions = 238) for the *Hayatori*. Dealing with the mean amplitudes (as seen in Tables 12 and 19), the slight superiority of the amount of vibrations of the *Harusame* is also apparent. Owing to the difference of range of revolutions, a rigorous comparison between the two vessels is not possible, but the following general averages of the 2a of the different orders shows such superiority in every instance:

Order of vibrations.	*Harusame.*		*Hayatori.*	
	Mean of all average 2a.	Mean of all maximum 2a.	Mean of all average 2a.	Mean of all maximum 2a.
	mm.	mm.	mm.	mm.
I	0.79	1.04	0.61	0.78
II	0.48	0.66	0.44	0.63
III	0.33	0.43	0.30	0.36

Relative Frequency of the Different Orders of Vibrations.—Table 23 is deduced from Tables 11, 16 and 17, by classifying the cases in accordance with the order of vibration.

TABLE 23.—Relative Frequency of the Various Orders of Vibrations.

Order of vibration.	*Harusame*, per cent.	*Hayatori*, per cent.	Order of vibration.	*Harusame*, per cent.	*Hayatori*, per cent.
I	12½	52	IV	0	2
II	41	37	V	0	1 (?)
III	37	8	VI	9½	0

One very noticeable difference, as brought out by Table 23, is the number of cases of the 3d and 6th orders in the *Harusame*, while in

the *Hayatori* the number of cases of the 3d order were few and cases of the 6th order were altogether absent. This difference may, very probably, be due to some slight want of balance in one or the other of the 3-bladed propellers of the *Harusame*. The prevalence of the 1st and 2d order vibrations is also to be noticed, the comparatively few cases of the 1st order in the *Harusame* being probably explained by the more limited range of revolutions in that vessel. As mentioned on page 98, vibrations of Order I nearly always existed to some extent, even when those of higher orders predominated.

Vibrations of Orders I and II.—The range of revolutions, between which 1st order vibrations occurred as principal vibrations, is fairly consistent in the two vessels; in the *Harusame* one case occurred at 212 revolutions, the others between 226 and 245 (245 being the highest recorded revolutions for this vessel); in the *Hayatori* the cases occur between 226 and 271 revolutions, and then again between 300 and 339 (nearly the highest recorded). Of 2d order vibrations the cases occur in groups; in the *Harusame* these are 122 to 128 revolutions, and 181 to 227; in the *Hayatori* 182 to 207, 254 to 257, and 326 to 342. (It should be remembered that the total range of revolutions throughout the experiments was 122 to 245 in the *Harusame* and 156 to 342 in the *Hayatori*.)

The figures 226 and 271, the lowest range of 1st order vibrations in the *Hayatori*, give a mean of 249 revolutions (corresponding vibrations = 249); the figures 122 and 128, the lowest range of 2d order vibrations in the *Harusame*, give a mean of 125 revolutions (corresponding vibrations = 250). Treating the *Harusame* and the *Hayatori* as under exactly similar conditions, this practical coincidence of the number of vibrations, during an active phase in each vessel, the vibrations being 1st order in the one case and 2d order in the other, is very suggestive. Mr. Yokota, a colleague in the Engineering College of the Tokio Imperial University, has worked out theoretically the number of vibrations of each vessel when oscillating with two nodes. His investigation for this case gives 225. The figure, though differing somewhat from the 249 or 250 derived as above, is close enough to suggest a possible connection between them, which might be established by more extended investigations.

Absolutely Greatest Motion.—The absolutely greatest vibration of the 1st order occurred in the *Harusame* at 244 revolutions ($2a_0 = 1.64$), in the *Hayatori* at 238 ($2a_0 = 1.60$). These numbers agree fairly well with the number 249 or 250 of the previous paragraph, and tend to emphasize the fact that at revolutions a little below 250 an active phase of 1st order vibration existed. Second order movements are less consistent with the figures of the previous paragraph. The absolutely greatest vibration of this order in the *Harusame* appeared at 200 revolutions, its amount being 1.28 mm., whilst the maximum vibration in the region of 125 revolutions was 0.48 mm. only; in the *Hayatori* the absolutely greatest vibration of the 2d order occurred at 341 revolutions ($2a_0$ = 1.00 mm.), an inferior maximum occurring also at about 200 revolutions ($2a_0$ = 0.80 mm.).

Intensity of Vibrations.—Concerning the maximum values of Tables 14 and 21 (*Harusame* and *Hayatori*, respectively), it appears that the maximum acceleration for each order of vibration was as follows:

1st Order.........	495 mm.	(per sec.)^2
2d "	2 210 "	"
3d "	2 270 "	"
6th "	4 360 "	"

These numbers represent the intensity of motion of a single vibration.

Admiral Melville has pointed out* that the intensity for a series of vibrations is force (or acceleration) and frequency; thus the relative intensities of the various orders become as follows:

1st Order..........	$495 \times 1 = 495$
2d "	$2\,210 \times 2 = 4\,420$
3d "	$2\,270 \times 3 = 6\,810$
6th "	$4\,360 \times 6 = 26\,160$.

The four numbers thus obtained have the mutual ratio 1 : 8.9 : 13.8 : 53.

* *Engineering*, January 9th, 1903.

Comparison of the Horizontal Vibrations of the *Harusame* and the *Hayatori*.

Comparative Amplitude.—The absolutely greatest vibration of the two vessels was the same, *viz.,* 1.2 mm., occurring at 176 revolutions in the case of the *Harusame* and at 180 revolutions in the case of the *Hayatori*. A comparison of Tables 15 and 22 shows little difference in the vibrations of the two vessels; a general average of all values of 2a of the 1st order for the two vessels gives the following:

	Harusame.	*Hayatori.*
	mm.	mm.
Mean average vibration......	0.46	0.43,
" maximum "	0.60	0.61,

in which the close agreement is at once apparent.

Effects Arising from Differences of Revolutions of Starboard and Port Engines.

In general, the vibrations, both vertical and horizontal, were not uniform. Occasionally they consisted of alternations of maximum and minimum amounts occurring at fairly regular intervals; this is illustrated by Fig. 12.

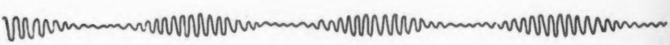

FIG. 12.

The occurrence of several maximum groups in succession seems due evidently to differences of revolutions of the starboard and port engines. If R and R' denote the revolutions, then T, the interval between two successive coincidences of phase, is given by

$$T = \frac{60}{R - R'}.$$

The interval between successive maximum amounts of vibration may be expected to be equal to T.

The following cases are taken from the experimental records.

Horizontal Vibrations of Harusame.—(*a*) Between 12.26½ and 12.32 P. M. alternations occurred as above referred to; the interval between maximum amounts was 5.2 sec., the vibrations being of the 1st order. The differences of revolutions, as given in Table 11, were, at intervals, as follows:

$$\begin{array}{lll} 12.26\tfrac{1}{2} \text{ P. M.} & 6 \text{ revolutions} & \\ 12.28 \quad `` & 8 \quad `` & \left.\begin{array}{l} \\ \\ \\ \\ \\ \end{array}\right\} \\ 12.29 \quad `` & 11 \quad `` & \\ 12.30 \quad `` & 13 \quad `` & \text{mean } 11.3 = R - R'. \\ 12.31 \quad `` & 16 \quad `` & \\ 12.32 \quad `` & 14 \quad `` & \end{array}$$

Hence, $T = \dfrac{60}{11.3} = 5.3$,

which merely agrees with the actual interval, 5.2 sec., already given, between successive maximum amounts of vibration.

(*b*) Again, between 12.30½ and 12.40½ P. M., the average interval between successive maximum amounts of vibration (Order I) was 5.1 sec.; the value of $R—R'$ was 11.5,

$T = \dfrac{60}{11.5} = 5.2$ sec., giving, again, a close agreement.

Vertical Vibrations of Hayatori.—Between 1.25 and 1.28 P. M. on June 4th, there were 13 maximum groups with an average interval of 13.9 sec.; the vibrations being of the 1st order. To compare with this the value of T is $\dfrac{60}{4.5} = 13.3$ sec., where 4.5 is the approximate $R—R'$ at the time indicated.

Vertical Vibrations of Harusame.—Between 1.58 and 2 P. M. the successive maximum amounts occurred at an average interval of 3.7 sec. At this time the state of motion was more complex than in the cases already considered; at 1.58 the predominating vibrations were of Order IV, while at 1.59 to 2 they were of Order II mixed with some of Order IV. To suit such cases the expression on page 114 must be modified to

$$T = \frac{60}{n\,(R - R')},$$

where n denotes the order of vibration. In the case now considered

the approximate value of $R—R'$ is 4. Hence,

$$\text{For Order II vibrations } T = \frac{60}{2 \times 4} = 7.5,$$

$$\text{" " IV " } T = \frac{60}{4 \times 4} = 3.7.$$

The interval, 3.7 sec., as actually found, is probably to be explained as due to the predominant part played by the Order IV vibrations.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING [CONGRESS,

1904.

DISCUSSION ON

NAVAL ARCHITECTURE.

By Messrs. L. E. Bertin, William P. Craighill,
E. L. Corthell, W. F. Durand and
Sir William H. White.

L. E. Bertin, Esq., Paris, France.* (By letter.)—Sir William White in his paper on the development of Naval Architecture during the last ten years presents his subject with such precision and in such a masterful way that the writer can hardly add anything, except, perhaps, what the author's modesty has kept him from saying, that is, the active part which he himself has taken in the rapid succession of improvements which he mentions. Mr. Bertin.

Without doubt, the merit of having kept brilliantly during this period, the naval supremacy acquired so long ago can, as Sir William White wishes it understood, be well credited to the whole of his country; to the unceasing and enlightened patriotism of the Admiralty; to the power of British industry; and to the enterprise and initiative of shipbuilders, as well as to the activity and skill of workmen, resulting from long practice. It is but just thus to praise the part taken by Great Britain, whose steamers of all classes, ocean greyhounds or the not less useful if less pretentious tramp steamers, cross the seas in all directions, and are so many connecting links between the several parts of an immense empire, and make of the ocean an extension, so to speak, of the dominions of the United Kingdom.

It is by having at all times in process of construction in the

* Ministère de la Marine de France.

Mr. Bertin. yards so many steamers, large and small, aggregating an average tonnage of 1 000 000 tons, that England revolutionizes the maritime commerce of the world, and, little by little, does away with the delays and uncertainties of sailboat navigation. It is by building boats patterned after Brunel's and Scott Russell's *Great Eastern*, some even of greater tonnage, but which, luckier than she, find ready cargoes to fill their holds, that English shipowners have been able to solve the difficult problem of reducing to 5 or 6 sous the cost of coal consumed in carrying 1 000 tons of freight a distance of 1 000 nautical miles, thus competing with the legendary cheapness of sailboat navigation.

The writer predicted some thirty years ago the decline of a mode of transportation to which the opening of the Suez Canal had dealt a severe blow. One might have thought that the opening of the Panama Canal would not be detrimental to sailboat navigation, but all that tends to shorten distances can only now increase steamship traffic.

England deserves, therefore, all the more credit for maintaining the first place, acquired over a century ago, since her competitors are more numerous and rivalry has become more acute. There was a time when she had to reckon with but one emulator; she may regret that happy time which France certainly regrets still more. If, among the 84 steamships of more than 10 000 tons which, in 1902, were a part of the world's merchant fleet, Sir William White could count 39 vessels flying the British flag, and 35 flying the German and American flags, we must concede that even in her palmiest days France was far from being so close a follower of Great Britain.

Competition, so keen in all economic questions, is keener yet among inventors. While the merchant service may soon find in Mr. Parsons' turbine the best and most adequate motor, the naval service owes to the United States its Harveyized plates. The improvements made in the rapid-firing gun are undoubtedly due to the Elswick works; but the smokeless powders which are probably the best and primordial cause of the evolution of this gun are, the speaker believes, the invention of Mr. Vieille. Lastly, if the Admiralty has changed the part played by the torpedo in naval tactics by introducing the destroyer, there is now at hand a more radical revolution, due to the appearance of the submarine boat conceived by Dupuy de Lôme, and realized in practice by his friend and collaborator, Gustave Zédé.

As to marine boilers, the writer's preferences being known since the *Jeanne d'Arc* and the *Jurien de la Gravière* were put on the stocks, he begs to be excused from adding anything to the remarks of Sir William White on that subject. In this case, the principal competitive models have had their prototypes in the same country,

if his recollections are correct regarding the inventions of Sochet Mr. Bertin.
and Du Temple, as well as those of Joessel, Belleville and Cottet. If any injustice is done to Messrs. Thornycroft and Yarrow, by placing them chronologically after the above inventors, the writer begs to be excused by pleading good faith; moreover, these gentlemen have so many inventions to their credit that they will not contend a small detail. The writer does not feel competent to say anything with regard to Messrs. Babcock and Wilcox.

The great permanent merit, the art, of the British Admiralty, is the recognition of innovations which may be useful to the English Navy, no matter whence they come, and, in its broadmindedness, in rising above all small and petty considerations, and in seeing only the extent of prospective results. In order to obtain such wonderful results, the Admiralty, after discovering men so useful to their country as Sir Nathaniel Barnaby and, after him, Sir William White, leaves them free to exercise their master minds, and knows also how to second their efforts and how to honor them.

If we consider how much he has accomplished, we may well say that Sir William White has no peer. He took the direction of naval construction at the time when the Admiralty foresaw the rapid development of the navies of the United States, Germany, Russia, and Italy, as well as of Japan, and when it pledged itself to attain certain results, no matter at what cost, indifferent also as to what reaction it might have on the construction of rival navies. Sir William White tells us about this gigantic work; how he found at his disposal, upon his re-entering the Admiralty, an appropriation of 100 000 000 to 110 000 000 francs per year, figures which were soon exceeded and reached annually an average of 150 000 000 francs for new construction alone, for seventeen years, from 1888 to 1904. Never before was man enabled thus to transform such masses of steel in so short a time, and few men would have been morally and physically fit to carry on successfully such an undertaking.

In his paper, Sir William White mentions rather briefly the execution of Hamilton's programme in 1889, remarking particularly on the successful completion of the work laid out in this programme within the fixed time and expense limits. He gives more space to the description of the work done after 1894, and in which his engineering skill has had more occasion to assert itself.

Sir William White's personal intervention is easily seen in the defensive system adopted on board the *Majestic,* which is so radically different from that used on board the *Royal Sovereign.* It is substantially a combination of the armor plating with the system of protection first used on board cruisers, that is with the protected deck, and to which, in 1873, the name, cellular zone, was given.

Mr. Bertin. The armored belt surrounding this zone protects it from the danger of explosives. The protective deck brought down to the base of the belt serves, moreover, to protect the vital parts of the boat. The perforation of the armor is not now-a-days as serious an injury as it used to be, and this permits the reduction of the thickness of the armor plate, especially since the adoption of Harveyized steel. The armor plate, being thinner, may have a greater area and may spread over the extremities and chiefly over the bow of the ship exposed heretofore to total destruction; it may also be brought up high enough toward the middle to insure the stability and protect effectively the light artillery. This is a new system, now accepted everywhere, which was first applied on the *Sardegna* by the Italian Navy, perhaps without developing all its consequences. This new disposition was not finally adopted in France until 1898, although it had been proposed and advocated as far back as 1890. Meanwhile, between 1890 and 1898, another but somewhat similar disposition was adopted on board the *Henri IV*. We have, therefore, two kinds of protection, each with its own merits, *sub judice lis est.*

What has been said of Sir William White's battleships applies also to the cruisers which he has designed, following the same lines. Here, particularly, he has successfully attained or even exceeded in all his latest models, the high speeds which had been specified.

Following in decreasing order the different sizes of ships, we find the same judicious conception in the specifications drafted by the Admiralty for the construction of destroyers. This work was given to constructors such as Messrs. Thornycroft and Yarrow, who were soon followed by scores of successful competitors.

The British Admiralty, regaining once more the lead which had been taken by other navies, brought to naught the efforts of those who had distanced her in the construction of a flotilla of torpedo-boats. The torpedo-boat catcher adopted everywhere has become a classical theme on which all constructors have worked. New models have been designed, among the best, those of Mr. Augustin Normand, but no navy has been able as yet to design a destroyer able to cope with the torpedo-catchers that the British Admiralty have just created.

Sir William White gives us a recent example of the watchfulness of England by mentioning the number of submarines under construction. In this class, we find boats somewhat outside the types recommended by Sir William White; in fact, the submarine was rather in disfavor among his advisers; but the old principle requiring that the superiority in numbers in all types of construction ruled in this case, as it will permanently rule at Whitehall.

In conclusion we may point out how, from the technical viewpoint, Sir William White can be justly proud of his conceptions

and bold initiative, how, also, he has always been careful in safeguarding England's supremacy; and it is again this same supremacy that he had in mind when he urged the Cunard Company to adopt the 60 000 h. p. turbines on the liners intended to wrest from the S. S. *Kaiser Wilhelm der Grosse,* the speed record temporarily held by the German steamer. Mr. Bertin.

In this new venture, as a fellow engineer, the writer wishes Sir William White complete success; as a passenger, the prospect of having the trip between the two hemispheres made still shorter is less pleasing; six days were not too long for one to get his "sea legs" on again, and to breathe in perfect quietness the pure air of the ocean. The possibility of going from Paris to London in a sleeping car without any change would certainly be more tempting, and its realization would be a decided advance and a red-letter day for the suffering public subject to the evils of sea-sickness. But such considerations do not stop an engineer bent on breaking records on a 30 000-ton liner; and we must reconcile ourselves to the prospect of going to New York in four days in the near future.

WILLIAM P. CRAIGHILL, PAST-PRESIDENT, AM. SOC. C. E., Charlestown, W. Va.*—Sir William White's paper is extremely interesting and instructive, and leads the speaker to make some comments upon it. Gen. Craighill.

In the paper, the *Great Eastern* and the distinguished man who designed her are spoken of with high praise. This brings to the speaker's recollection his wonder at that ship, and his admiration of Brunel, on the occasion of her first visit to the United States, nearly fifty years ago, about 1858 or 1859. He saw her at anchor off Annapolis, the highest point at which it was safe for her to be in Chesapeake Bay. Many distinguished men went from Washington to see her there, very probably even the President of the United States. She was then drawing about 28 ft. The depth in the channel to Baltimore was then only about 17 ft. at mean low water, and the range of the tide did not average over 18 in. When she came again, she could have reached the dock at Locust Point in Baltimore in safety, as a greatly increased depth had been given to the channel, a work that was in charge of the speaker for many years.

The speaker's admiration for the marine architect was greatly increased when he first crossed the Atlantic in the old *Celtic* of the White Star Line, in 1879, and this admiration was not to be wondered at when, standing on her deck at midnight, he saw one man on the bridge, who with one hand was guiding this great outcome of the brain of a man—one other man in the depths below was regulating the engine that kept her in motion—while the crew and the pas-

* Retired Chf. of Engrs. and Brig.-Gen., U. S. A.

Gen. Craighill. sengers, some 1 200 or 1 500 in number, were quietly sleeping below.

It was somewhat appalling, however, to see this monster of the deep plunging along at the highest speed in the pitchy darkness of midnight. When the speaker ventured to suggest to the captain that the conditions as to safety might be improved if he had such an arrangement as the headlight of a railway locomotive capable of use when necessary or expedient, he smiled at the ignorance and presumption in such a suggestion, and yet we now see the search-light much used in that way.

Again the speaker ventured to suggest that if one screw was so efficient in giving speed, why not have two or more? The captain promptly replied that there was no space available for the additional machinery that another screw would make necessary; and yet we now hear of a second and third screw for steamships. The world moves, and it is the contrast of present conditions with the past that enables an intelligent man to realize the advances made in marine architecture under the influence of such men as Sir William White.

And these contrasts will impress one; for example, the speaker's voyage in 1879 on the *Celtic,* which was a fine ship for her time, called to mind the preceding experience which he had had on a long voyage in 1864, when he sailed from New York to Aspinwall (now Colon) on the Isthmus of Panama. The ship was an old side-wheeler of small tonnage, and was greatly inferior to the *Celtic* in every way. But in those days of war, the Government of the United States had need of all available ships that were of value, and passengers and commerce had to take what was left, and this was often very poor. This old side-wheeler, named the *North Star,* was famous in her way, as she had once been captured off the eastern point of Cuba, Cape Masi, by the Confederate Admiral Semmes. The captain of the *North Star* was reported to be on good terms with Semmes, and for that reason the ship was not burned, but was allowed to depart after giving bond for a large sum to be paid when the independence of the Southern Confederacy should be acknowledged—the speaker has not heard of the money having been paid.

The speaker has had to do with a great many rivers and harbors on all the coasts of the United States, and his rule has always been, before undertaking to give a certain depth of channel, which is in all cases dependent upon an intelligent use of the forces of Nature, assisted by jetties and the dredge, and the outcome of which can seldom or never be forecasted with accuracy, to consult with the people who are the best judges of the commercial requirements of the locality under consideration, and after hearing their wishes as to the draft of ships desired, his effort has been to do what they wanted as far as possible, having due regard also, as an agent of the

General Government, to other than mere present or prospective local interests, but looking forward also to what might be reasonably expected in a greater development of commerce. And this brings up another point to be considered in connection with the relations of the work of the marine architect and that of the engineer engaged in improving natural channels and making artificial ones; and this arises from the difference in commercial conditions between the conservativeness of an old, steady community, and the progressiveness of a new, growing country like ours. Take, for example, the improvement of the channel to Baltimore. This channel had a depth of 17 ft. at low water when the speaker first went there and took charge of the work; and the business men of the community and the people interested in the steamships said they wanted 22 ft., which we could give them without any trouble with the dredge. We depended upon the dredge entirely, because jetties were not permissible under the conditions. Before we had reached a depth of 22 ft., and this took years, because we were dependent to a very great extent upon the appropriations of the General Government, which are spread over so large an area that the progress is slow at any one locality, they said "We must have a 24-ft. depth." The speaker replied, "All right, if you will get the money we will get the 24 ft. very promptly." The business men of the City of Baltimore promptly asked, "How much more money do you want than the Government supplies?" The speaker said, "If you will give me $400 000 you shall have the 24 ft. in a year." We had hardly finished the channel with a 24-ft. depth before they said, "We must have 27 ft." The speaker replied, "All right, get the money." And they did, and we soon had the 27 ft. The same thing went along until they got 30 ft., and now they want 35 ft., and they ought to have it in order to accommodate the largest ships, like the *Baltic* and others which the marine architects have built, or will build. Gen. Craighill.

E. L. Corthell, M. Am. Soc. C. E., New York City.—The speaker wishes to confirm, not criticize, Sir William White's statements. His investigations have been made along lines entirely different from those of the paper under discussion. Mr. Corthell.

In order to show the usefulness of his results, the speaker would need to give a brief *résumé* of his work begun six years ago at the request of the Permanent Secretary of the American Association for the Advancement of Science, who had asked him to write a paper for the fiftieth anniversary of the Association upon the subject of the development of maritime commerce.

The speaker being in Europe at the time, undertook the work, spending a month in the British Museum studying "Lloyd's Register" and the Bureau Veritas, and another month in the Library of the Institution of Civil Engineers. The result of these first inves-

Mr. Corthell. tigations was a paper entitled "Maritime Commerce, Past, Present and Future." In this paper, he showed the development by tables and graphical exhibitions on seventeen different lines from 1848 to 1898, and predicted what the development would be in the succeeding twenty-five and fifty years.

It seemed necessary, in view of the remarkable past and future development of steamships, to inquire if the ports of the world were adequate to meet the enlarged dimensions of vessels. The investigation was undertaken to ascertain this, and a correspondence was entered into with 131 ports. The result of this work appeared in a paper presented to the International Navigation Congress at Paris in 1900 entitled "The Harbours of the World: Their Present and Required Conditions of Navigability and Facilities." In this paper the speaker gave a brief review of the former paper, and tables showing the existing and proposed conditions of the ports.

The speaker is now engaged in correspondence with 218 ports of the world, with steamship companies, naval architects and others, asking for data to enable him to write a paper particularly covering the last half decade, on the subject of "Maritime Commerce, Development in Dimensions of Vessels, Existing and Proposed Dimensions of Ports." This paper is to be presented to the Tenth International Navigation Congress to be held at Milan, Italy, in September, 1905.

These various investigations confirm all that Sir William White said in his Presidential address before the Institution of Civil Engineers about the development of the merchant marine of Great Britain and the world, and also the statements made in reference to channel and port depths.

While not wishing to anticipate his forthcoming paper, the speaker would remark that analyzing in various ways the increase in number, tonnage, average tonnage, dimensions and draft of steamships, they are greater than he predicted half a decade ago, a prediction which at the time was considered by some as somewhat imaginative and exaggerated.

Prof. Durand. W. F. DURAND, ESQ., Stanford University, Cal.*—Among the wide range of topics discussed, the speaker purposes to add only a few supplemental remarks regarding the discussion of "Estimates of Speed and Engine Power."

Reference is made in Sir William White's paper to the desirability of model experiments in experimental tanks, and to the valuable indications which may be reached by work of this character. The English have long been pioneers and leaders in experimental research of this character, while in the United States opportunities for such research are only recent in date. During the past

* Professor of Mechanical Eng., Leland Stanford Junior University.

Prof. Durand.

few years, the speaker has been able to carry forward certain experimental researches of this character, and desires to confirm the opinion expressed by Sir William White regarding the great importance and high potential value which such investigations may have. The purely mathematical theory of ship resistance and propulsion has been developed about as far as seems possible on the basis of known facts, and the present need seems to be not so much for greater refinements in pure theory as for more facts on which to base a practical or working theory for every-day use; and it is such facts that an experimental plant of the character referred to should be able to provide. There is, moreover, especial need for experimental establishments of this character operated under such auspices as will insure freedom to pursue definite lines of investigation without interruption by the needs of dealing with special cases and particular commercial problems. It is unfortunate that in practically all the governmental experimental tanks most of the energies must, by the very necessities of the case, be expended on the examination of specific problems arising in connection with definite and specific cases of design, and that but little opportunity is left for the examination of problems of a more fundamental character. There are, in fact, a large number of such problems, most important in character, which have relation, not to any one commercial case, but which rather lie at the very foundation of a large part of the work of the naval architect and marine engineer, and it is certainly most desirable that institutions should be fostered where research of this broad fundamental character may be carried on without disturbance from specific commercial problems.

Reference is also made to the "fresh weight which has been given to this argument by the introduction of rotary engines with high speed of revolution, demanding propellers of unusual dimensions in relation to the power applied." This forms at the present time one of the important new problems for the designer of the screw propeller. So long as the propeller is worked under what are commonly taken as standard conditions of proportion and slip there exist data sufficient to insure a design with a reasonable probability of efficient operation; but the instant excessive speeds of revolution, or unusual proportions are involved, or, in short, anything lying outside the beaten path of experience, uncertainty is at once introduced. To reduce this area of uncertainty, further experiments are certainly needed in this particular branch of the field. Reference is made by the speaker to this topic by reason of the fact that he has recently been called upon to investigate certain cases of propellers of very unusual proportions with regard to pitch ratio, the values of this ratio all lying below 1 and reaching down as far as 0.25. The results are most interesting, and although not yet fully

Prof. Durand. reduced give indications that while, as in all other lines of engineering work there is a broad pathway leading to failure, there are still evidences of a relatively narrow way by which satisfactory efficiency may be realized. The permissible range of operation will perhaps be less than with propellers of more common proportions, but within limits there are hopeful indications that reasonably satisfactory efficiencies may be attained with propellers of quite abnormally low values of the pitch ratio.

Sir W. H. White. SIR WILLIAM H. WHITE, PRESIDENT, INST. C. E., London, England. (By letter.)—The discussion on the writer's paper calls for few remarks in reply, but his thanks are due to M. Bertin, whose kindly appreciation of the paper and of the writer's professional work is the more valued, because he is recognised as the leading French naval architect of the present day, upon whom rests the responsibility for the designs of the ships added to that great navy. M. Bertin, in his published works on naval architecture and marine engineering, has shown a range of knowledge and high professional culture which makes his contribution to this discussion important; and his intimate knowledge of the progress of French invention, as well as his acquaintance with British naval architects and marine engineers, enhance the importance of his statements as to the relative dates of the work done by various inventors. Undoubtedly the interchange of information, which is now happily established between the naval architects and marine engineers of all civilised countries, results in the contemporaneous improvement in the details of ships and their machinery, and makes the claim to absolute priority more difficult to decide than heretofore.

General Craighill's remarks, being largely based upon personal experience gained in a high official position occupied during a long period with conspicuous success, are of much interest. It may be hoped that other engineers charged with works on harbours, rivers, and the approaches to ports will adopt the rule which General Craighill followed; and, before deciding upon the depth of water to be provided and other accommodations required, will consult those who are good judges of the commercial requirements of the locality, and at the same time provide a margin considerably beyond that which may be immediately necessary.

Mr. Corthell has given such close study to the development of the mercantile marine and the appropriate accommodation to be provided for it in docks, harbours, rivers and canals, that his opinions must command exceptional respect.

Professor Durand has been a close student of the theory of ship resistance and propulsion, and, in recent years, has done much in experimental research; so that his concurrence in the views expressed in the writer's paper will undoubtedly carry great weight

Sir W. H. White.

amongst his fellow countrymen who are connected with ship-building. His latest investigations on propellers with unusually small pitch ratios, and adapted for use with machinery having exceptionally high rates of revolution, should prove of great practical value in connection with the use of steam turbines and internal combustion engines; and, taken in connection with the experiments made by Naval Constructor Taylor, at the United States Navy Yard, Washington, should be of great assistance to those who have to deal with vessels propelled on these systems.

It is a great satisfaction to the writer that a paper, which was primarily intended to be a record of the progress made during the last ten years and a statement of our present position, should have elicited these expressions of opinion from such competent authorities.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS, 1904.

PURIFICATION OF WATER FOR DOMESTIC USE.

Congress Paper No. 48.

AMERICAN PRACTICE.

By Allen Hazen, M. Am. Soc. C. E., New York City, U. S. A.

Congress Paper No. 49.

EUROPEAN PRACTICE.

By Dr. Adolph Kemna, Manager, Antwerp Water-Works Company, Antwerp, Belgium.

Congress Paper No. 50.

INVESTIGATIONS FOR GROUND-WATER SUPPLIES.

By J. M. K. Pennink, Director, Amsterdam Water Supply, Amsterdam, The Netherlands.

Congress Paper No. 51.

FRENCH PRACTICE.

By M. Bechmann, Ingénieur en Chef des Ponts et Chaussées, Chef du Service des Eaux et de l'Assainissement de Paris, Paris, France.

Discussion of the Subject by

ANDREW HOWATSON, Paris, France.
GEORGE C. WHIPPLE, New York City, U. S. A.
EDWIN O. JORDAN, Chicago, Ill., U. S. A.
EDMUND B. WESTON, Providence, R. I., U. S. A.
L. J. LE CONTE, Oakland, Cal., U. S. A.
J. P. A. MAIGNEN, Philadelphia, Pa., U. S. A.
J. N. CHESTER, Pittsburg, Pa., U. S. A.
ROBERT SPURR WESTON, Boston, Mass., U. S. A.
GARDNER S. WILLIAMS, Ann Arbor, Mich, U. S. A.
RUDOLPH HERING, New York City, U. S. A.
F. L. FULLER, Boston, Mass., U. S. A.
E. E. WALL, St. Louis, Mo., U. S. A.
JOHN F. WIXFORD, St. Louis, Mo., U. S. A.
GEORGE W. FULLER, New York City, U. S. A.
ALLEN HAZEN, New York City, U. S. A.
DR. ADOLPH KEMNA, Antwerp, Belgium.
M. BECHMANN, Paris, France.

NOTE.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 48.

PURIFICATION OF WATER FOR DOMESTIC USE.

AMERICAN PRACTICE.

By Allen Hazen, M. Am. Soc. C. E.

Although something had been done in the United States in water purification before 1890, the development of the art, from a theoretical, experimental and practical standpoint, has been so rapid since that time that it has completely overshadowed what had been done before, and a statement of its development in the past decade needs but little extension to cover the whole history of water purification in the United States.

A few small sand filters, following European precedent more or less closely, had been constructed before that time. In addition to these there was a much larger number of filters of an entirely different type. This type was that commonly known as the mechanical filter, and sometimes as the American filter. Its essential features are filtration at a much higher rate, in connection with a preliminary chemical treatment of the water.

The characteristic result of this chemical treatment, or coagulation, was the gathering of the particles of suspended matter in the water into aggregates, which were removed more easily than the indi-

vidual particles. The application of this chemical treatment was an American invention, and the general process founded upon it is the most successful one for the treatment of very turbid water. Ten years ago, although the process had been in use for some years, little progress had been made in the knowledge of the conditions essential to success with it, and the filters in use founded upon this system were crude, and, from the present standpoint, generally inefficient.

Experiments.

The experimental study in water purification has been one of the most striking features in the history of the past decade, and one of the largest elements in the progress attained. These experiments have been carried on in various parts of the country and with different kinds of waters. Different conditions and methods have been investigated, and the results have formed the foundation of much of the present art of water purification.

The first of these experiments were those at Lawrence, Mass., carried out by the Massachusetts State Board of Health. The plan of these experiments was conceived by Hiram F. Mills, C. E., and they have been continued to this date under his general direction. T. M. Drown and W. T. Sedgwick have been associated with them, while the writer, G. W. Fuller, M. Am. Soc. C. E., and H. W. Clark have been successively in direct charge af the experiment station. These experiments related entirely to sand filters and were made upon water from the Merrimac River, a water highly polluted by sewage, but comparatively clear. The results of some of the earlier experiments were described at the International Engineering Congress at Chicago, 1893,* and were applied in the design of the Lawrence, Mass., City Filter.

These experiments were followed by those at Louisville, Ky., made jointly by the Louisville Water Company and certain companies interested in the construction of mechanical filters. Mr. G. W. Fuller, under the direction of Charles Hermany, President Am. Soc. C. E., represented the water company. These experiments were made entirely with mechanical filters, and with a water considerably polluted by sewage, and often extremely turbid, and they formed the basis of modern mechanical filtration.

* *Transactions*, Am. Soc. C. E., Vol. XXX, p. 350.

Shortly afterwards, experiments were made at Pittsburg, Pa., by Morris Knowles, M. Am. Soc. C. E., and the writer, representing the city, with the co-operation of several filter companies; and at Cincinnati, Ohio, by Mr. G. W. Fuller, under the direction of G. Bouscaren, M. Am. Soc. C. E., with both sand and mechanical filters, and with waters varying considerably in their qualities, being sewage-polluted and also, at times, quite turbid.

More recently, experiments have been made at Washington, D. C., by Lt.-Col. A. M. Miller, Corps of Engrs., U. S. Army, M. Am. Soc. C. E.; and at New Orleans, La., by R. S. Weston, Assoc. M. Am. Soc. C. E., with the supervision of Mr. G. W. Fuller, along similar lines, but with new types of apparatus and with arrangements suggested by the earlier experiences. The results of all these experiments have been published. There have also been many minor experiments in various parts of the country, and some experiments have been made, the results of which are not available to the public.

In the last years of the decade the experimental evidence has been supplemented largely by results obtained from plants in actual service which are operated with scientific supervision, and of which full records are kept. The information of this kind is limited to the last few years, because prior to that time no filter plants in America were operated in that way.

Relative Applicability of Different Kinds of Filters.

At the beginning of the decade there was a strong rivalry between the advocates of different systems of filtration, and many believed that one system or another was best, and should receive universal support. The experimental researches have cleared up this situation. It has been clearly and unmistakably proved that for the treatment of very turbid waters the sand filters successfully used in Europe and on the clearer waters of the Eastern part of the United States are inadequate. This point is particularly important, because many American cities have raw waters which are turbid far beyond the limits of those European supplies which have largely served as precedents in water purification. This turbidity can be removed by chemical treatment, and that is the only known process which is able to do it successfully. On the other hand, for the treatment of the sewage-polluted, but comparatively clear, waters of many

eastern streams, sand filters have yielded the best hygienic results. The relative advantages and applicability of the two processes were outlined in a report by Rudolph Hering, M. Am. Soc. C. E., G. W. Fuller, M. Am. Soc. C. E., and the writer, upon the purification of the water supply of Washington, D. C.

The idea of relative applicability expressed in this report may be carried much further. The purification of water consists in the removal from it of objectionable matters. The matters which most commonly require to be removed are (1) turbidity and suspended matter; (2) color; (3) bacteria, particularly those from sewage; (4) tastes and odors, and the microscopical organisms which produce them; (5) iron; and (6) lime and magnesia, constituting hardness.

These different kinds of matter to be removed are very different in their chemical and physical natures, and, to remove them, different lines of attack must be followed. The problem is much more complex because the same water often contains impurities of different kinds mixed in varying proportions, and the absolute and relative amounts often vary greatly at different seasons of the year.

Developments in the Design of Sand Filters.

At the beginning of the decade sand filters had been developed in Europe to a well-established type, but there were no filters in use in this country of the most advanced designs. A large part of the advance in America has consisted in copying methods and arrangements which had been used previously in Europe, but, in addition, many advances have been made in this country, quite aside from European practice.

A marked tendency of the decade has been toward the use of covers for filters, even in places where the winters are not very severe. It was recognized earlier that covers were essential where the winters were very cold. The idea has gained ground, and is expressed in many extensive constructions, that covers are desirable in climates less severe than those in which they were formerly regarded as necessary; and, although a large additional cost is involved, the additional security of operation and the possibility of employing the labor required for their operation constantly and without stopping for any weather, however unfavorable, is a practical advantage which goes a long way toward offsetting the additional first cost.

The use of concrete groined arches in the construction of covers, previously practiced in Europe to a limited extent, has been adopted widely in the United States and with the most satisfactory results. Groined arches of brick were first used by William Wheeler, M. Am. Soc. C. E., in the construction of small filters at Ashland, Wis., and Somersworth, N. H. Concrete groined arches were first used in the United States by the writer at Albany, N. Y., where George I. Bailey, M. Am. Soc. C. E., was Superintendent of Water-Works, and William B. Fuller, M. Am. Soc. C. E., was Resident Engineer for the construction of the filters; but there was European precedent for the work. Leonard Metcalf, M. Am. Soc. C. E., has shown the advantages of this type of construction. The construction is strong enough to meet the most exacting requirements, while its cost is so little that it seems doubtful if any other type of construction can compete with it successfully. Roofs of concrete reinforced with steel have sometimes been used, but with this construction the strength which can be obtained by a given expenditure is probably less than in the simple concrete arches.

One of the most important developments has been in the apparatus for the control of filters, that is the apparatus which indicates and controls the rate of filtration, the water levels and the flow of water in the plant. Good regulating apparatus for this service is essential to the satisfactory operation of filters. Without it, irregularities occur which seriously interfere with the quality of the work performed. Apparatus for this purpose had been developed and used in Europe at an early date. Some of the apparatus since constructed in this country has been copied more or less closely from European models. In addition, principles of regulation have been developed in this country quite different from those in use in Europe, and have found extended and successful use. The use of the Venturi meter in connection with this control is an important development.

The American practice has been, on the whole, toward the use of apparatus which is only partially automatic, as such apparatus is simpler and possesses important advantages over that which is entirely automatic, while the additional attention required is not an important matter where men must, in any case, be kept constantly on duty.

Accurate knowledge of the sand required for the best results has

been obtained almost entirely in the past decade. Prior to that time sand was selected for filters simply by the eye, and many inferior results were obtained because the sand was not well adapted to the service. The experimental researches of the decade have shown clearly the range of sand sizes adapted to successful use with different waters and under different conditions, and specifications have been written and hundreds of thousands of cubic yards of sand have been furnished conforming accurately to the conditions necessary for the best results.

American practice in regard to the depth of filter sand and gravel underneath has differed somewhat from European precedent. There has been a tendency to use a thicker sand layer and less gravel. These changes were suggested by the experiments at Lawrence and computations based upon them. The sufficiency of the thinner gravel layer and the advantages of the thicker sand layer have been demonstrated in practice. In the best American practice the depth of gravel is usually only 12 or 15 in., while the sand layer is 3 or 4 ft. in thickness.

In recent designs the gravel which supports the sand has been kept away from the walls of the filters, allowing the sand to go to the floor for a short distance. In the earlier filters, where this was not done, whenever a crack appeared in the filter wall it served to carry unfiltered water, entering above the sand and discharging into the gravel connected with the underdrains below. With the new arrangement the water in passing from the crack to the drains must go through the sand upon the floor, and because of its weight the sand will always maintain a close contact with the floor, and there is no chance for open channels to exist, and a good degree of purification of such water is thus assured. It is difficult to say how far some of the inferior results of the older filters were due to this cause, but it is certain that modern filters constructed under careful conditions produce very much better results than some of the older ones, and the differences are such as cannot be entirely accounted for by differences in the kind and thickness of sand, or in the rate of filtration. They must be attributed, in part at least, to the greater care taken in all details to prevent the passage of unfiltered water through cracks into the pure-water channels, and to the better devices for maintaining even rates of filtration.

A great development has taken place in the apparatus for handling sand. At the beginning of the decade the surface layer of sand, with its accumulation of impurities, was taken off by hand, and carried in wheel-barrows to an area outside the filter where it was washed. There were no good washers in use in the United States ten years ago. The introduction of the ejector washer at Lawrence in 1895, the first design being based upon European models, marked the beginning of this development. Soon after it was found that instead of always wheeling sand to the washer it was possible to use a movable ejector connected with the principal part of the apparatus with wrought-iron pipe in short lengths. Afterward, hose was used in place of the iron pipes. The movable ejector was carried around to the sand piles in the court, and the discharge from the ejector was arranged to pile the sand up at the required points. This reduced largely the labor required in connection with sand washing. The next step was to arrange the movable ejector so that it could be carried to all parts of the filter so that the dirty sand could be thrown directly into it. The ejector then forced the sand to the washer, and the wheel-barrows were entirely eliminated. In the newer plants permanent pipe lines are provided for the longer runs in this system, while the shorter connections are made by hose. This development has to a large extent followed European precedent, for sand elevators, conveyors and washers, embodying the principles, at least, of most of those since used in America, were in use, in European works, more than ten years ago.

The details of the sand washers have also been considerably developed. The ejector type of washers has come to be universally used. Originally, in this type of washer, in each hopper the sand was separated from a part of the turbid water which brought it, and was mixed with a corresponding quantity of clean water. There was thus always a dilution of the turbid water, and this dilution was repeated a considerable number of times until the remaining quantity of dirt was inappreciable. In the most recent designs the dirty sand falls into a rising current of clean water which entirely displaces the dirty water which brought it, and a better cleaning is obtained with fewer operations and with less water.

These developments in the methods of handling and washing sand have been such that the work is better done, and with less than

half the labor required by the methods which were in use at the beginning of the decade.

There seems to have been some tendency toward the use of higher rates of filtration during the past decade. On the continent of Europe the rate of filtration has been limited commonly to 100 mm. per hour, or 2.57 million gallons per acre daily. In England the rates have perhaps been a little higher. In the United States, as a result of experiments at Lawrence and elsewhere, a rate of 3 million gallons per acre daily has been generally used as a standard maximum rate, although for the filtration of clear and but slightly polluted waters, such as lake and reservoir waters, the rates have been twice as great.

A recent development is the use of preliminary filtration in connection with much higher rates of filtration. The purification works for Philadelphia, Pa., John W. Hill, M. Am. Soc. C. E., Chief Engineer, which are the largest thus far undertaken in America, are based on the use of such preliminary treatment, followed by filtration at a rate of 6 million gallons per acre daily. It is thought that the results obtained will be as good, while the reduction in the required area of filters will more than cover the expense of the preliminary treatment. The idea has also been advanced that these methods of preliminary treatment could be extended so that very turbid waters could be clarified without the use of chemical treatment. But these are matters of the future rather than of those actually accomplished.

Developments in the Design of Mechanical Filters.

The developments in mechanical filters have been so extensive as to amount to an entire rearrangement of the type of filter. At the beginning of the decade the water received a chemical as it went to the filter. This treatment was covered by a patent issued February 19th, 1884, to Isaiah S. Hyatt. Sometimes the water went through a basin on the way to the filters, but in these cases the basin was so small as to be merely nominal and of but little practical importance. The water, after receiving the chemical, went downward through the filter and was collected by a strainer system below. The filter was washed from time to time by a reverse current of water applied through the same strainer system which removed the effluent. The washing was usually aided by the mechanical agitation of a rake driven by power.

The time allowed for the chemical reactions to take place was very short; consequently, for efficiency, a relatively large amount of chemical was required. The relations between the amount of chemical used and the alkalinity of the water were not understood, with the result that the adequate coagulation of waters of low alkalinity was impossible and was in fact rarely undertaken. Practically adequate coagulation was seldom carried out. Such coagulation may have been used occasionally for some special purpose, but in ordinary use the amounts of coagulant used were only a fraction, oftentimes only a small fraction, of the amounts necessary for efficiency. The ordinary operation of the filters was thus reduced to a mere straining, entirely inadequate to remove the bacteria or disease-producing properties of the water.

The experiments with filters of this type carried out during the decade have shown the relations between the amount of coagulant required and the impurities of the water upon which the coagulant acts, and the relations between the amount of coagulant which can be used and the alkalinity of the raw water have also been ascertained; and when the natural alkalinity of the water is deficient, provision is made for increasing it to such an extent as may be necessary for the use of the amount of coagulant required for complete purification.

By the use of much larger coagulation and settling basins the chemical reactions take place satisfactorily with smaller quantities of coagulant than were required with the smaller basins formerly used, and they are also more complete, and the bulk of the impurities is deposited in the basins and the work of the filters is lessened.

The advantages of double coagulation in some cases have been shown, particularly by the experiments at Louisville. It was there found that if the heavier sediment of extremely turbid waters is removed by sedimentation before the coagulation takes place, the process can be carried out with less coagulant than where it is applied at the start. It has also been found that, with very turbid waters, if the coagulant is applied in two parts, with a period of action and settling between, better results with a given amount can be obtained than with the application of coagulant at one point only.

In the construction of filters there have been radical changes. At the beginning of the decade the filters were generally constructed

in wooden tanks. Later, in some cases, steel tanks were used. At the end of the decade the best practice is, clearly, the use of concrete or steel-concrete construction, and many of the newer plants are built in this way. Among the newer filters, built of masonry and designed in the light of knowledge derived from the experimental investigation, may be mentioned the filters at Louisville, designed by Charles Hermany, President, Am. Soc. C. E.; the filters of the East Jersey Water Company at Little Falls, N. J., designed by G. W. Fuller, M. Am. Soc. C. E., acting for the Water Company, and Mr. Charles L. Parmelee, acting for the contractor, under the direction of J. Waldo Smith, M. Am. Soc. C. E., Chief Engineer; and the smaller plants at Ithaca, N. Y., that for the university, designed by G. S. Williams, M. Am. Soc. C. E., and that for the company supplying the city, designed by the writer. In connection with this change in the material with which the tanks are built, the piping and the whole strainer systems have been built in a more adequate and substantial manner.

The mechanical agitation in the newer plants is generally secured with air introduced into the bottom of the filter, either by a modification of the strainer system or by a separate system of air pipes. The results obtained seem to be as good as those obtained with rakes driven by power, while the application of air in a large plant is much simpler and cheaper. Parts of several plants built for operation in connection with air have been operated without air for considerable periods. In these cases the only agitation of the sand has been that furnished by the upward movement of the water in washing. The results have shown that this arrangement would not answer under all circumstances, but in some cases they have been quite favorable and have suggested that the air might be dispensed with under certain conditions and perhaps with certain provisions for an occasional more thorough washing of the sand.

Mechanical filters require good apparatus for their control, quite as much as sand filters. The clogging of the sand and the increase in frictional resistance take place much more rapidly than in sand filters. These changes are too rapid to allow adjustment by the attendant, and it is imperative to have the apparatus entirely automatic. The requirements differ considerably from those of sand

filters, and the controllers used have been entirely of American invention, and have been developed to meet very perfectly the required conditions. The controller designed by Edmund B. Weston, M. Am. Soc. C. E., and extensively used in the plants of the New York-Continental Jewell Filtration Company, is one of the most notable of those used during the past decade.

Some of the most important improvements have been in the apparatus for feeding coagulant. Successes with this system of filtration depend absolutely upon the uninterrupted supply of coagulant in the required amount to the entering water. One of the commonest sources of failure has been the interruption of the supply of coagulant, either through failure of the apparatus or carelessness of the attendants. Substantial progress has been made in developing appliances for the accurate control of the amount of coagulant and in making them so substantial and automatic in operation that they can be taken care of with the minimum trouble and liability of failure, but there is still room for improvement.

Improvement has also been made in the general construction to prevent the accidental contaminations of water after filtration. Many of the earlier plants were defective in this respect. Filtered water was sometimes carried in open channels below the filters with opportunities for matters to fall into them, and the clear-water basins were often placed directly under the filters, with only a wooden floor between, so that the wash and slop on the floors could go through, carrying whatever dirt might be upon them. In the newer plants great pains have been taken to prevent this condition, while in some cases the pure-water reservoirs have been placed at one side, and all the channels and places through which the filtered water passes have been closed and entirely protected from accidental pollution.

In bacterial or hygienic efficiency, the earlier mechanical filters left much to be desired. Some of the newer and better ones are doing as good work as corresponding sand filters. This statement applies to efficiencies as disclosed in the laboratory. They have not yet been long enough in service to allow an adequate test by the cruder, but perhaps more certain, test of the effect which they produce upon the health of those who drink the water.

Developments in Preliminary Processes.

The preliminary processes of water purification have come to be looked upon as far more important than was the case ten years ago. It has been learned that the coarser matters can be removed by comparatively simple processes, and that when they are so removed the water passing to the filters is of a better and more uniform quality, and the work of the filter is improved, both in quantity of output and in quality of effluent.

First among preliminary processes is sedimentation. At the beginning of the decade a sedimentation basin consisted of a reservoir holding a certain quantity of water, through which the raw water flowed on the way to the filters, and in which the coarser sediment was deposited. It has been learned that the shape and arrangement of the basin are of the greatest importance. These matters are often controlled by the use of baffles. Baffles are partitions, usually of plank, incapable of sustaining a water pressure, and not entirely water-tight, but so arranged as to make the water follow a certain systematic course in passing through a basin, and arranged to prevent the entering water, with the maximum quantity of sediment, from becoming mixed with the water already partially cleared. The improvement obtained in this way is very great. A well-baffled basin will probably do as much work as a basin twice as large without baffles.

A comparatively recent development is the use of scrubbers. Scrubbers may be described as coarse filters, or strainers, or refined sedimentation basins, through which water passes at a comparatively rapid rate, and which remove the coarser particles of sediment. The results that can be accomplished in this way may be better than can be reached in sedimentation basins, and the apparatus can be arranged in a smaller space and has many advantages. One of the most important practical problems in connection with scrubbers is the removal of the matter which accumulates in them. Otherwise the sediment removed from the water would stop them in a comparatively short period. Practice as to scrubbers, and the methods of cleaning them, is not as yet well established. J. P. A. Maignen, Assoc. Am. Soc. C. E., has designed and constructed, under general specifications, scrubbers now in service at works supplying a part of Philadelphia.

Coagulation is a preliminary process, and the developments in regard to it have been already mentioned in connection with mechanical filters. Coagulation has a field of its own, however, aside from its use in connection with mechanical filters, and it has been recommended and probably will be used sometimes in connection with filters of other types. Its use in this way will be limited to periods of unusually bad water, and will make it possible to secure, at such times, better results than could otherwise be obtained.

The development in the chemistry of coagulation in the past decade has been rather in a better understanding of the different phases of the process than in the use of new substances as coagulants. Sulphate of alumina has been the principal coagulating material. In connection with it, lime or soda-ash are often used to supply the alkali to combine with the acid of the coagulant, where such alkali is not present in sufficient quantities in the water under treatment. Alum has been used in place of sulphate of alumina in some small filters, but never in any large modern plant.

Many attempts have been made to substitute salts of iron for those of alumina, and this has been done to a limited extent. Several plants have been operated with iron dissolved with the acid of fumes from burning sulphur. Copperas (ferrous sulphate) one of the by-products from the manufacture of galvanized wire, has been more successfully used. The use of copperas depends upon the oxidation of the iron from the ferrous to the ferric state by the dissolved oxygen of the water treated, and this oxidation only takes place when the water is somewhat strongly alkaline. It is thus necessary to use lime at all times in connection with this coagulant.

A large number of other substances produced chemically or by electrical discharges have been proposed, and some of them have been investigated experimentally in the United States, but as they have not been successfully used in practice, a consideration of them does not properly enter this statement.

Iron Removal.

The removal of iron from ground-waters has been an important development of the past decade, and quite a number of plants have been installed. The general method used is that previously developed in Northern Germany, where many ground-waters contain iron. It

consists in the aeration of the water, resulting in the oxidation of the iron from the ferrous to the ferric state, after which it is easily removed by filtration. Filters of different types are used for the final filtration, and the rates of filtration can be high, because the precipitated iron is flocculent and very easily removed. The works at Reading, Mass., and at Asbury Park, N. J., and those of the Queens County Water Company, Far Rockaway, N. Y., and of the Superior Water, Light and Power Company, Superior, Wis., are examples of this kind of purification.

Softening.

No important municipal softening plant is in use in the United States. A few such plants have been recommended, and as the waters available for public supplies in many parts of the country are very hard, it is probable that such plants will become numerous in the future.

Developments in Methods of Operation.

One of the greatest advances in the art of filtration has been in the methods of operation. At the beginning of the decade all the purification plants in the United States were in comparatively untrained hands, and were operated more or less inefficiently. The experimental investigations of filtration served to show what could be done by well-operated plants, and they also served to show how easily and certainly inferior results were obtained when the operation was not well managed. Some of the newer and better plants have been equipped with laboratories for the examination of water before and after filtration, and for testing various matters in connection with the process, and technically trained men have been put in control, so that the operation has been followed with the same care and attention that has been used in the experimental plants.

The advantages of this procedure are very great. Not only is the regular work better and more certain, but it is sometimes secured at less expense than would be possible without trained supervision, and although the number of plants operated in this way is as yet small, it may be confidently expected that the system will be extended to all important works.

The idea is often advanced that the use of filtered water from a polluted source is necessarily unsafe because of the difficulty or im-

possibility of securing proper operation. But the same argument applies with equal force to railroads. There is precisely the same difficulty in getting men of the necessary intelligence and faithfulness to drive the locomotives, to set the signals, and to do a thousand things, the neglect of which would bring disaster. In comparison, the problem of filter operation is simple, and one that can be solved with as little risk to those who drink the water as there now is to the passengers upon a railway train.

Statistics as to the Use of Filters.

The growth in the use of filters in the United States is shown in Table 1, compiled from the best data at the disposal of the writer. These data are only approximate, as many matters necessary to a full and complete statement cannot be ascertained at this time, but they are believed to be sufficiently accurate to give a correct idea of the rapidity of the development. The populations supplied with filtered water in the cities of the United States at several dates, excluding a few cities where the filters were particularly inefficient, are shown in Table 1.

TABLE 1.

Year.	Total urban population in the U. S. (Towns above 2 500).	Population Supplied with Filtered Water.			Percentage of urban population supplied with filtered water.
		Sand filters.	Mechanical filters.	Total.	
1870	.....	None.	None.	None.	0
1880	13 300 000	30 000	.....	30 000	0.23
1890	21 400 000	35 000	275 000	310 000	1.45
1900	29 500 000	360 000	1 500 000	1 860 000	6.3
1904	32 700 000	560 000	2 600 000	3 160 000	9.7

The population supplied with filtered water has been increased 70% in four years. There is reason to believe that it will be increased by an equal percentage in the next four years.

Table 2 has been prepared to show the condition of the present water supplies of the larger cities in the United States. The classification is in accordance with the best obtainable information, but no doubt many matters have been overlooked, so that the classification must be regarded as only approximate. Where a city has several supplies, the population has been distributed as nearly as possible in proportion to the quantity of water used from each source. Probably the results of more complete information would show a

TABLE 2.—SUMMARY OF FILTRATION OF WATER IN THE UNITED STATES, FEBRUARY, 1904, THE FIGURES IN EACH CASE REPRESENTING THE POPULATION.

Cities with populations of:	Number of places.	Total population, census of 1900.	Filters in Service.		Filters under Construction.		Filters Authorized.		Filters recommended officially.	Filters needed now or probably will be needed.	Filters probably not needed for a long time.	Filters not needed with present water supply.
			Sand.	Mechanical.	Sand.	Mechanical.	Sand.	Mechanical.				
Over 1 000 000	3	6 429 474	140 000	80 000	1 193 697	....	....	....	2 050 600	1 698 575	1 266 602	....
200 000 to 1 000 000	16	5 366 335	....	....	278 718	204 731	236 761	613 006	660 093	2 359 631	1 013 395	....
100 000 to 200 000	19	2 412 538	49 528	248 308	387 971	....	....	....	257 382	559 268	661 109	248 972
50 000 to 100 000	40	2 709 338	139 880	141 290	....	115 171	30 000	50 167	284 341	753 629	861 482	333 378
25 000 to 50 000	83	2 839 933	31 091	737 894	16 000	44 885	....	....	41 459	777 485	592 060	599 059
Totals for cities with populations over 25 000	......	19 757 618	360 499	1 207 492	1 876 386	364 787	266 761	663 173	3 293 875	6 148 588	4 394 648	1 181 409
8 000 to 25 000	356	4 946 091	118 290	841 103	....	....	....	....	....	....	....	....
2 500 to 8 000	1 136	4 834 032	34 564	322 891	....	....	....	....	....	....	....	....
Totals for places with populations over 2 500	......	29 537 741	513 353	2 371 486	....	....	....	....	....	....	....	....

slightly larger number of filters in use and under construction, and a considerable addition to the number of places where filters have been officially recommended, and some readjustment in the other columns.

The filters in service, under construction and authorized will serve populations as shown in Table 3:

TABLE 3.

Cities with populations of:	Sand filters. (Population.)	Mechanical filters. (Population.)	Total population.	Percentage of total population of cities of this class.
Over 1 000 000	1 333 697	80 000	1 413 697	22
200 000 to 1 000 000	515 479	817 737	1 333 216	25
100 000 to 200 000	437 499	248 308	685 807	28
50 000 to 100 000	169 880	306 628	476 508	18
25 000 to 50 000	47 091	782 779	829 870	29
8 000 to 25 000	118 290	841 103	959 393	19
2 500 to 8 000	34 564	322 891	357 455	7
Totals	2 656 500	3 399 446	6 055 946	21

Table 3 shows a tendency toward the use of sand filters in the larger cities and toward the use of mechanical filters in the smaller cities. This tendency is, perhaps, more apparent than real, for it may be that the larger cities use sand filters because more of them are in the East, where their water supplies are comparatively clear, and where sand filters are well adapted to the service; while the greatest development in mechanical filters has been on the rivers of the Mississippi Basin, and in the South, where large numbers of comparatively small cities have filtered their water supplies, and where the raw waters are turbid to such an extent that sand filters are not applicable.

The increase in the number and capacity of purification works in the future is sure to be very rapid. In 1900 the population supplied with filtered water in the United States was about six times as great as in 1890, and the plants in use at the latter date were, on an average, probably much more efficient than those in use at the earlier date. The increase in filtering capacity since 1900 has been even more rapid, and more filters are now under construction than ever before. Already nearly 10% of the urban population of the United States is supplied with filtered water. Filters are under construction to supply a further 8%, and there is plenty of opportunity for exten-

sion, as is shown by Table 4, which is a statement of the condition of water supplies in cities of more than 25 000 inhabitants.

TABLE 4.

	Total population.	Percentage of total population.
Filters in service, February, 1904	1 567 991	7.9
Filters under construction	2 241 173	11.4
Filters authorized	929 934	4.7
Filters recommended officially	3 293 875	16.7
Filters needed now or will be needed if present sources of supply are continued. Quality of water not satisfactory	6 148 588	31.1
Filters probably not needed for a long time. Quality of water reasonably satisfactory	4 394 648	22.2
Filters not needed with present water supply. Quality of water good	1 181 409	6.0
Totals	19 757 618	100.0

In addition to the population served by the filters constructed and under construction, water of a more or less unsatisfactory quality is now supplied to approximately 52% of the urban population of the United States in cities of more than 25 000 inhabitants; and, while some of these supplies will be replaced by those from unpolluted sources, it may be confidently expected that a great majority of them will be continued in use, and that purification plants will be constructed for their treatment. The water supplies of a further 22% of the population, while of a more satisfactory character, would be improved by filtration; and, as the standard of purity is advanced, it is to be expected that filters will be installed for the treatment of a large part of them. The remaining 6% of the urban population is supplied with water from sources which may be reasonably regarded as entirely satisfactory, and no thought of purification is entertained. The proportion of the population in cities and towns with less than 25 000 inhabitants supplied with entirely satisfactory water is probably greater than in the larger cities, because a much larger percentage of them is supplied with ground-water, which, from a hygienic standpoint, is generally satisfactory.

Cost of Filtration.

During the decade there has been a wonderful advance in the design and management of purification plants. The effect of these

changes has had two effects upon the cost. On the one hand more exacting requirements have constantly led to the use of better and more adequate appliances and to more thorough systems of operation, and this has tended to increase cost. On the other hand, improvements in design and the development of mechanical appliances to perform parts of the work formerly accomplished by hand labor, have tended to reduce cost. On the whole, it is, perhaps, fair to state that the improved methods and the increased efficiency have been secured without any material change in the cost of the process, although, of course, there are many exceptions, some in one direction and some in the other.

As a general average, with a well-designed modern plant, adapted to its work, the cost of filtering water, exclusive of pumping, but including all costs of operating the filters and furnishing the supplies required, and including the interest on the cost of the works, and a reasonable allowance for repairs and depreciation, will amount to about $10 per million gallons, or one cent per thousand gallons of filtered water. Occasionally, with a very easily treated water, and with conditions favorable for cheap construction, the cost may be as low as $6 or $8 per million gallons. On the other hand, with waters which are difficult to treat, or where the conditions of construction are difficult, the cost may be increased to $15 or even $20 per million gallons. In a general way, the purification of the water adds from 10 to 20% to the entire cost of furnishing and supplying water to an American city. The percentage is usually less as the works for securing the water are more extensive. Where water is carried long distances (the absolute cost of purification remaining the same) the percentage is much less than where water is obtained from sources in the immediate vicinity. This cost of filtration, although a small percentage of the whole cost of water-works, has been large enough to prove a substantial obstacle to the adoption of filters in many cases.

There is a practical consideration which has tended to make the cost of filters in American cities much greater than it would otherwise be. This is the waste of water. The quantity of water supplied is often from 150 to 250 gal. *per capita* daily. It has been demonstrated in many cases that the actual quantities of water used are not more than from 60 to 80 gal. *per capita* daily. In fact there are many large cities which supply no more water than this to their inhabitants. The difference between the quantity of water actually re-

quired for the uses of a city, and the quantity supplied, represents waste. A part of this is lost by leakage from the joints in the pipes, and a part flows through defective or leaky fixtures in the plumbing in the houses of the city. The quantity of water which may be lost in this way may easily be several times as great as the actual quantity required for use.

The means to be taken to reduce waste and limit the supply to a quantity only moderately in excess of the actual requirements are well known to water-works men, and can be applied. The reason that they have not been applied more generally and effectively is that a badly informed public resents any attempt to prevent the waste of water. It requires education to bring people to distinguish between the curtailment of use and the suppression of waste. The two things are absolutely different, and no one would think for a moment of taking steps to reduce the use of water. But the two things are confounded, and the water-works superintendent who advocates and practices the suppression of waste is likely to become unpopular, and men in these positions have been unwilling to carry through the policy even when they have fully recognized its advantages.

The bearing of this point upon filtration is indirect but important. If a city requires 60 gal. of water *per capita,* daily, to supply its use, and wastes 120 gal., making 180 gal. to be provided in all, the cost of purification will be nearly three times as great as if the waste were suppressed. It is not quite three times as great because the costs are not quite in proportion to volumes, and a small plant is usually a little more expensive in proportion than a large one.

The unrestricted waste of water leads to a large amount of trouble even when the source of water is near at hand, and when no cost beyond the cost of pumping is incurred in maintaining the supply. But when filtration becomes desirable and necessary, this waste becomes a very formidable obstacle to carrying out the works, and has done much to retard the progress of water purification in America. On the other hand, the necessity for filtration has been an element of importance in bringing to the front the question of preventing waste, and in leading to a discussion of it, and to a better understanding of the problem; and it may be confidently expected that the policy of American cities will improve in this respect.

FILTRATION FROM THE STANDPOINT OF HYGIENE.

The best known and most apparent effect of an impure water supply is to produce a high typhoid fever death rate among those who use it. When a polluted water supply is well filtered, and thereby made wholesome, the typhoid fever death rate is reduced. The general death rate, as might be expected, is also reduced, and it is reduced to a greater extent than can be accounted for in the reduction of the typhoid fever rate. The percentage of reduction in the general death rate is less than it is with typhoid fever, and it is therefore more difficult to follow the relation, and the reduction attributable to the change in water can be ascertained with less certainty.

Tables 5 and 6 show the general death rates and the death rates from typhoid fever in a number of cities, before and after radical improvements in their water supplies. In four cases, two in Europe and two in the United States, the changes were made by the installation of sand filters. In the other cases the changes were from polluted river supplies to upland waters from unpolluted sources, or to ground-water. The year of change (when both the old and new supplies were in use) is omitted in each case. At Lowell, Mass., where the change was more gradual, two years are omitted, and at Hamburg, the cholera year, 1892, which immediately preceded the year in which the filters were put in service, is also omitted from the comparison.

TABLE 5.—DEATHS FROM TYPHOID FEVER PER 100 000 PER ANNUM.

Place.	Date of change.	Five years before change.	Five years after change.	Percentage of reduction.
Zurich, Switzerland...... Filtration.	1885	76	10	87
Hamburg, Germany...... Filtration.	1892–93	47	7	85
Lawrence, Mass.......... Filtration.	1893	121	26	79
Albany, N. Y.............. Filtration.	1899	104	28*	73
Lowell, Mass., River water to ground water....................	1895–96	97	21	78
Newark, N. J., River water to upland water........................	1892	70	16	77
Jersey City, N. J., River water to upland water	1896	77	24	69
Averages......................	....	85	19	78

* Four years.

The reductions in death rates with the installation of filters have been quite as great as in those cities where the new sources of supply

were from unpolluted sources. The average reduction in the typhoid rate was 66 per 100 000. The reduction in the general death rate was 4.7 per 1 000, or 470 per 100 000.

TABLE 6.—DEATHS FROM ALL CAUSES PER 1 000 PER ANNUM.

Place.	Date of change.	Five years before change.	Five years after change.	Percentage of reduction.
Hamburg, Germany..... Filtration.	1892-93	24.0	17.7	26
Lawrence, Mass..........Filtration.	1893	24.4	20.0	18
Albany, N. Y.............Filtration.	1899	22.3	18.4*	17
Newark, N. J., River water to upland water.....................	1892	25.1	22.1	12
Jersey City, N. J., River water to upland water..................	1896	25.4	19.3	24
Lowell, Mass., River water to ground-water.............................	1895-96	25.1	20.5	18
Averages.....................	....	24.4	19.7	19

* Four years.

While the reduction in the typhoid rate is 66 per 100 000, that in the general death rate is 4.7 per 1 000 or 470 per 100 000, or seven times as much. Where there is one less death from typhoid fever there are six less from other causes.

The writer believes that the whole of the reduction in the typhoid rate should be attributed to the change in water supply, because cities similarly situated, which have not improved their supplies, have experienced no permanent reduction in their typhoid fever rates. With the general death rate the case is different. Improved general sanitary conditions have reduced the death rates in recent years, and the normal reduction in a period of six years, which represents the average elapsed time between the first and second series of results, would account for a part of the reduction in the general death rate.

The average reduction in the general death rate between 1890 and 1900 in eighteen cities having from 50 000 to 300 000 inhabitants, in New England, New York and New Jersey, which made no radical change in their water supplies, was 2.28 per 1 000. This is computed from the report on Vital Statistics in the United States Census of 1900. Assuming a uniform decrease in rate in the interval, the average, or what we may call the normal, reduction, in 6 years would have been 0.6 of this, or 1.37 per 1 000. In comparison with this, in five cities where the water was radically improved, the reduction in

the same period was 4.4 per 1 000. The results may be tabulated as follows:

	Death rate per 100 000 living.
Reduction in total death rate in five cities with the introduction of a pure water supply	440
Normal reduction due to general improved sanitary conditions, computed from average of cities similarly situated but with no radical change in water supply	137
Difference, being decrease in death rate attributable to change in water supply	303
Of this, the reduction in deaths from typhoid fever was	71
Leaving deaths from other causes attributable to change in water supply	232

This computation indicates that where one death from typhoid fever has been avoided by the use of better water, a certain number of deaths, probably two or three, from other causes have been avoided. This seems the clear and logical conclusion from the statistics. It is not easy to explain how the water is connected with the deaths other than those from typhoid fever. It may be that a good water supply, used freely, and with confidence, results in a better general tone in the systems of the population, and so indirectly to a lower death rate, and that a part of the reduction is represented by diseases having no recognized connection with the quality of the water supply.

The results that have been achieved by the filter plants which have been best constructed and operated have been all that could be desired. Waters polluted by sewage, and most injurious to the health of those drinking them in their raw state, have been purified so that the resulting death rates from water-borne diseases have been no greater than in cities of corresponding size and situation, supplied with water from the very best sources. If any disease is caused by the waters filtered in this way, the amount is too small to be measured or determined by the methods now at our disposal.

While the most satisfactory results have been obtained in a limited number of the best works, the results obtained by the great

majority of the filter plants in this country have been inferior; the quality of the water has been improved, and often greatly, but the results have fallen short of those obtained in the best plants, and, beyond a reasonable doubt, sickness and death have been caused by the use of imperfectly filtered water.

It must thus be considered that a great part of the filtration now practiced in the United States is inadequate, and it is probable that a great many of the older filters will be reconstructed or replaced with filters of better design in the course of the next decade. It is also to be expected that as knowledge regarding these matters becomes more definite and certain, and is more generally distributed, the methods of operation of filters will be improved and the efficiency of water purification works will be increased.

The use of raw water from the sewage polluted rivers of the country is a filthy and unhealthy practice. It results in thousands of unnecessary deaths among the people who drink it. The sanitary objection to the use of water from these rivers has increased many fold in the past generation. These rivers are often the most available and in some cases the only sources of supply. Filtration is the most powerful agent at our disposal for meeting this increase in pollution. With well-built and well-operated works it is a most efficient agent, and allows supplies to be obtained from polluted sources, which are, as far as can be ascertained, as satisfactory from a hygienic standpoint as any waters obtainable.

Filtration also has a large field of usefulness in the purification of less polluted supplies, which, from the standpoint of a few years ago, were of such quality as to require no treatment, but which, under more exacting requirements, are looked upon with less and less favor.

The development of purification works has been so rapid that already nearly 10% of the urban population of the country is supplied with filtered water, and works are under way and authorized which will bring this to more than 20 per cent. The development, although rapid, has only begun, and it may be confidently expected that in the course of the next generation, possibly, even, in the next decade, purification works will be so far extended that the greater part of all the water used for public supplies in the United States will be treated before use. The gain in the wholesomeness of the supplies, and in the security of life in cities, makes this work one of the most useful which can be undertaken.

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PURIFICATION OF WATER FOR DOMESTIC USE.

EUROPEAN PRACTICE.

By Dr. Adolph Kemna.*

The location of centers of population, which have grown in the course of centuries to be large cities, has been influenced largely by the possibility of obtaining water, a prime necessity of life, easily. The facilities of communication by watercourses, as well as the geological formation of districts, explain the seemingly irregular distribution of towns.

The great importance of a general water supply was fully appreciated in ancient times. The remains of huge works in a series of arches of a broken aqueduct is a classical feature in any picture of the Roman Campagna or of an Eastern landscape. Large volumes of water, taken from springs, were carried through miles of country to supply ornamental fountains and public baths. We know what value was attached to the water, by the fact that great cleverness was shown by dishonest men to get more than their share, and by the officials striving to prevent it. A book on the water supply of Rome, by Julius Sextus Frontinus, the Water Commissioner under Nerva, has come down to us through the monks

* Manager, Antwerp Water-Works Company.

of Monte Cassino, the manuscript of which has been splendidly edited.*

The Moors continued the practice of the Romans, and Spain, for example, was splendidly irrigated and covered with water-works. Each Calif, not only maintained former works, but made it a point of honor to improve and to add; while later the Christian kings allowed the works to decay.

Practically, in the dark centuries of the Middle Ages, the whole elaborate plant came to grief. When civilization dawned again in Western Europe and cities became populous and rich by industry and trade, new works were started, but on a much smaller scale. The great demand for bodily cleanliness and public baths had fallen off, and small quantities sufficed for limited wants. Instead of distant springs, the nearest surface water was taken. Belgium has two of the oldest supplies at the formerly wealthy towns of Bruges and Ypres in Flanders, dating back from the 13th century.

Such works became more numerous in the 16th century and were a specialty of Dutch Engineers. Peter Moris, who first supplied London, was a Dutchman. He simply took the water from the Thames at London Bridge. Paris took water from the Seine and many other towns were supplied from similar sources. Probably the two last works of some importance for such supplies, were the Canal de l'Ourcq for Paris, under the first Bonaparte, and that of Hamburg in 1847.

The first attempt toward sanitation was generally the replacing of cesspools by sewers emptying into the nearest watercourse. This wholesale contamination of the rivers brought its own punishment, by polluting most water supplies.

At the beginning of the decennial period which it is intended to review, it had long been an article of faith that surface waters, being open to contamination, were always dangerous to health and life. The rapid growth of bacteriological science had shown the reasons for this. Especially in two zymotic diseases, typhoid and cholera, had the influence of drinking water been clearly shown. Koch discovered the comma-bacillus of cholera in the Calcutta ponds in 1883 and Brouardel stated in 1889 that 90% of typhoid cases owed their origin to contaminated water. The period con-

* Clemens Herschel, "Frontinus and His II Books on the Water Supply of the City of Rome." Dana, Estes & Co., Boston, 1899.

sidered opened under the deep impression made by the disaster at Hamburg, the cholera of August, 1892, which was a practical demonstration on a large scale. The somewhat vague theories of Pettenkoffer on the generation of zymotic disease were most cruelly crushed. At the same time, the maintenance of satisfactory sanitary conditions in the adjoining town of Altona, showed that ordinary sand filtration was a sufficient safeguard. The experience thus gained at the cost of over ten thousand human lives, was made the more valuable as the above conclusions were vouched for by the high authority of Geheimrath R. Koch, in his articles in the *Deutsche medicinische Wochenschrift.* The late Andreas Meyer, the Municipal Engineer of Hamburg, gave a full history of the supply,* and showed with much courage, how local politicians, moved by private interests, interfered for years with the bettering of the supply. All surface waters must be considered dangerous and their use in the raw state for a general supply, in each particular case, either has been, is now, or is likely to be, the cause of disease and death.

Great amelioration is obtained by prolonged storage, by settling, and probably also by the sterilizing effect of light. This is what happens in lakes, natural or artificial. Especially in England, the system of large reservoirs has been applied: for example, the Staines Reservoir for several of the London companies. Also in Germany, especially in the industrial district of the Ruhr, where several dams have been erected by Professor Intze, of Aix-la-Chapelle.

In several cases, this process gave rise to great trouble; but this it seems was because the principle was not rightly applied. An expanse of water like Lake Michigan must give a better decantation than that which can be obtained with an artificial structure; yet Chicago was constantly visited with typhoid. The intake was under the direct influence of sewage, and its removal farther into the lake brought only temporary relief.

Remscheid is one of those German cities supplied by an impounding reservoir, and had typhoid in two consecutive years. A special feature of that reservoir was the location of the outlet at a rather low level in the dam and the carrying of some small streams directly to the outlet, through pipes at the bottom of the

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* *Schilling's Journal*, 1894.

reservoir. These arrangements were made probably with a view of securing at all times a water of equal temperature. But when in a settling basin, water is drawn from below instead of from above, part at least of the benefit of decantation is lost; and when some of the water is carried directly to the outlet, there is no decantation at all. Professor Intze contends that there was no connection between the water supply and the disease, because a careful search failed to detect the specific germ in the water; but it would have been interesting to enquire, whether there had not been some typhoid in the water-shed of those streams carried directly to the outlet. However, Professor Intze himself must have felt that there was a weak point, for the use of these pipes has been discontinued, and, on the contrary, a preliminary filtration (by irrigation on meadows) is recommended.*

Quite a similar case occurred at Verviers, an industrial town near Liege (Belgium), supplied by the Barrage de la Gileppe, the masonry dam being one of the thickest in existence and decorated with a huge monumental lion in the midst of the dam, like a cat on a garden wall. A small stream, the Borchène, joins the outlet pipe, so that its waters have had no decantation at all. In the winter of 1898, a severe epidemic of typhoid broke out at Verviers, the cases numbering several hundred. It was found that the Village of Yalkay, on the Borchène, must have contaminated the water. Consequently, that stream was cut off and another stream, on which there were also unfavorable conditions, was diverted through a separate canal; so that now the lake receives water from uninhabited ground only.

This tends to become a general practice, and most towns supplied by impounding reservoirs strive to clear their gathering grounds as much as possible. After the Maidstone scare in 1897, when all water-works in England reconsidered their position, many small improvements were made. Visitors and tourists were excluded from the grounds and fishing stopped in the lakes.

Two questions have become prominent of late years, *viz.*, the utilization of flood waters, and covering the catchment areas with forest.

A spell of heavy rain sends to the rivers enormous quantities of water in a short time, causing periodical flooding of the lower

*Congress, German Assoc. Gas and Water Engineers, Düsseldorf, 1902.

grounds. But these waters are avoided as much as possible by water-works engineers, on account of their muddy state. With proper storage allowing sufficient decantation, there is no reason why these waters should not be utilized. The arguments against this practice were strongly put, but were not strong by themselves and there is now a reaction against former exaggerations. In England and also in Germany, there is now a marked tendency to consider reservoirs as much a necessity for regulating the flow of rivers, as a means of a supply.

Covering catchment areas with forest is advocated as a means of regulating the yield and purifying the water, also as a source of some revenue to the water authority holding the land. But the question is an intricate one, and it does not appear that all the points have been carefully considered. In summer, when foliage is thick, most of the heavy rain is taken up to moisten the leaves and is then rapidly evaporated; so that the regulation of the yield is obtained by curtailing what the summer rains would add to the storage. The yellow color of the water in autumn, in several places in the United States, has been attributed to decaying leaves. However, within a few years, we shall have facts instead of suppositions.

There is a biological side to a surface water supply. The growth of plants and animals in lakes has been made the subject of scientific study and constitutes an important part of limnology. The practical application to water supplies of the knowledge so gained has been much neglected in Europe and in England, while in America it has received due recognition. Whipple's book* embodies the result of what has been done in that direction. Bad odors and tastes are caused by floating organisms, especially blue algæ and some flagellates. It is, however, a poor consolation to the consumer to know by name the various organisms he gets through his tap. These organisms are troublesome also in another way: Floating eggs, larvæ and seeds settle in the pipes and grow to fixed colonies. Some twenty years ago, Berlin and Rotterdam, by using insufficiently filtered water, had their pipes blocked up by *Crenothrix;* and at present, in that part of the Liverpool mains which carries the water from Lake Vyrnwy to the filters at Oswestry, the scraper has become a regular institution.

*George C. Whipple, "The Microscopy of Drinking Water." John Wiley & Co., New York, 1899.

Underground waters and springs are in strong contrast with surface waters. They are of constant temperature and composition. The natural action of the soil has deprived them of their organic pollution and they can be had practically sterile. Springs were deified by the ancients and something of this feeling remains, in the belief that they needs must be naturally pure and wholesome. Not only in popular circles, but also amongst water engineers and hygienists do we find the dogma of the absolute purity of springs. All European towns try to get them for their supply.

Intense disappointment has often been the result, and no better instance can be quoted than Paris. There, for half a century, the theory of the original purity of springs reigned supreme, and was consistently applied, irrespective of cost. But it soon became apparent that the summer yield had been greatly over-estimated, and the deficiency had to be made up with crude Seine water. The river water was as much as possible restricted to well-defined districts, so as to avoid contaminating the whole of the supply. It was enforced upon the officials to give preliminary warning of such substitutions, and the Socialist majority of the Municipal Council decided that only rich quarters, where people have the leisure to boil their water or can afford to drink mineral waters, should receive river water. It was only in 1899 that this practice was completely abandoned.

But in the meantime another problem of still greater importance had been enforced upon the attention of hygienists: The purity of the springs themselves was questioned. Water engineers and scientists outside of France had not shared the unrestricted confidence of their Paris colleagues; they were not satisfied with the sources of most of the springs. Coming out of porous and irregularly fissured limestones or chalk, the waters seemed open to surface contamination, and ominous warnings were sometimes given; especially at the Brussels Geological Society* it was clearly predicted that the Avre scheme would be a constant danger. But both the engineers and the theoretical hygienists in France disdainfully ignored these warnings, or met them with the severest rebukes.

Theories are only temporarily stronger than facts, and the facts rapidly accumulated and became overwhelming evidence. Repeated

*See especially the publications of the Société belge de Geologie, Paléontologie et Hydrologie of Brussels.

recurrence of typhoid fever strongly suggested the contamination of the various supplies. In 1900, an exhaustive enquiry was started; up to now three reports have been issued and liberally circulated, which is not customary with official publications in Europe.*

These reports constitute a valuable addition to water-works literature. With praiseworthy frankness, the real state of things was disclosed, confirming the worst anticipations; but in France they created quite a sensation in medical and hygienic circles. The foundations of science were shaken when it had to be admitted that springs, not only could be, but actually had been, dangerous, and that the indiscriminate use of springs from the chalk had been a gross mistake. The characteristic of the French literature of the last three years is the painful recognition of this truth.

The Paris case does not stand alone. The majority of towns in France are no better off. Everything is centralized in Paris, and the "Conseil Supérieur d'Hygiène" enforced its ideas upon the whole country. England contributed an example of what want of proper care in the protection of springs can bring about. The fearful epidemic of typhoid at Maidstone (Kent), in September, 1897, affected 5% of the population, a proportion rarely reached. In Germany last year there were epidemics at the Gelsenkirchen Barracks and at Metz, where the Emperor interfered personally in his usual energetic way.

The evil having been recognized, the next question is how to mend it. At Paris, Duclaux insisted on placing the whole of the districts supplying the waters under constant medical supervision. The springs have been made deeper; the superficial aqueducts, which took in a good deal of bad water, have been overhauled. The filling of the most dangerous swallow-holes with sand, and the paving of miles of watercourses over porous ground have also been advocated.

In Belgium, the question of a supply from limestone has been to the front for several years. The Brussels suburbs separated from the town proper and made a supply of their own in 1898. They took the waters from the valley of the Bocq, a tributary of the Meuse, halfway between Namur and Dinant. The scheme met with a good deal of scientific opposition, the more so as French ideas seemed to have been somewhat predominant. But great care

*Commission scientifique de perfectionnement de l'observatoire de Montsouris. *Travaux sur les eaux de Paris*, 1901-1903.

was exercised in selecting the waters, and protecting the catchment galleries against contamination. The new supply has, up to the present time, behaved satisfactorily. This is attributed to the special nature of the ground, being carboniferous limestone, in which large caves are absent and swallow-holes comparatively rare. It is also contended that all the fissures are filled with fine material ensuring perfect filtration, and that the whole is naturally protected by a sufficiently thick cover of quartenary strata. Devonian limestones act differently; the celebrated Grotto of Han, and several others nearby, are in these limestones.

The International Congress of Hygiene at its meeting at Brussels, in September, 1903, discussed also the question of waters from limestone, and recognized that special care was required for the hygienic maintenance of such supplies.

A very special feature in Germany during the last years is the tendency to return to underground waters. This has been applied to Berlin, where the surface waters of the Lakes Tegel and Muggel have been abandoned and water secured by a series of wells. But these waters have one great drawback: they often contain sulphuretted hydrogen and iron. The water comes out of the ground quite clear, but turns bluish and opalescent by the precipitation of the iron. In a certain number of towns, artificial aeration has been resorted to, and the precipitated iron oxide is then retained by straining through sand. There seem to be great differences in facilities of working; in some places the separation takes place easily, while in some others there is often difficulty. The question has not been thoroughly examined from the chemical point of view. Probably a good deal depends on the special nature of the compound, and on the nature of the acid with which the iron is combined to form a soluble salt. If the acid be comparatively strong, such as peaty acids, the combination is more stable, and it is difficult to precipitate all the iron; on the contrary, if the acid be weaker, the salt is more easy to decompose, especially the carbonates, as they are dissociated with mere aeration. The physical state of the precipitate, whether coarse or fine, is also an important feature practically. In one case, the removal of iron was exceedingly easy, and, at the same time, there was a reduction of hardness. The explanation is obvious: the salts were bicarbonates, and the fine

oxide of iron was taken down by the thick precipitate of carbonate of lime.

There is not much variety in the plant. An ingenious method of working a certain number of wells at the same rate by a single pumping station has been applied by the well-known Dutch engineer, H. P. N. Halbertsma, at the industrial town of Tilburg, in the south of Holland. Aeration is ensured by running the water over some kind of material so as to expose a great surface; coke, brick or tile and thick wood shavings have been used; the latter has in some cases given trouble by decomposition and bacterial growth; it seems better to exclude organic substances.

The whole system may be considered as very safe from the hygienic point of view. The underground water can be had bacteriologically pure, and all that happens later, as, for example, the trouble with the wooden shavings, is quite immaterial, and is moreover easily remedied. It is no doubt an improvement on a sand-filtered surface water supply, but it is a question whether that improvement is at present sufficiently important to justify the large expenditure. To this question, the engineers themselves give no direct reply. The change has been forced upon them by the influence of hygienists, and for reasons more theoretical than strictly practical.

The old time-honored system of sand filtration has been the subject of scientific investigation, more especially in Germany. The same depth is kept over the sand. Special attention is paid to working the filters as regularly as possible, with a constant and even flow. The outlet was formerly simply a sluice-valve, the foreman controlling the delivery by the number of turns of the spindle. This system has now become quite elaborate, sometimes automatically regulated, and registering the loss of head and the flow, so that the engineer, or more generally the bacteriologist, knows exactly at any moment what is going on.

The improvements in bacterial analyses have allowed the work of the bacteriologist to be a regular feature in most Continental water-works. In Germany and Holland, a permanent control has been made compulsory. But the practical value of bacterial analyses is most seriously lessened by the necessity of waiting three days before the gelatine plates can be counted. When a filter shows

unsatisfactory results, by the time these results are obtained, the filter may have become good again. Very naturally, an attempt has been made to shorten that period of waiting, and to secure more rapid and therefore more useful information. The presence of *Bacterium coli* can be detected in 24 hours, and recently Miquel, at Paris, has proposed to judge the efficiency of filtration by that test, as in normal conditions, the effluent is free from that special microbe.

Efficient filtration is more difficult in winter than in summer; this is easily accounted for by the important part biological actions are now known to play in the purification; these biological actions are diminished by cold. The ice on the filters is more troublesome, and cleaning a filter under these conditions becomes expensive. One of the Hamburg engineers, Herr Mager, devised an apparatus for scraping the surface of the sand without emptying the filter; a similar system has been used at the Waelhem station for the Antwerp filters. The periods of sharp frost can be gone through in this way without spoiling the filters.

The few well authenticated cases where a sand-filtered water caused disease, all occurred during the winter. The last example was at Rotterdam, in the beginning of the present year, 1904, when there was a large number of typhoid cases, and the specific *bacterium* was discovered in the water. At Rotterdam, the city owns the works, there are no meters, and consequently a large consumption. The filters have rather coarse, ordinary, river sand, much coarser than the fine dune sand used elsewhere in Holland; the filters are worked at a somewhat high speed; the sand is never washed, it being cheaper to recharge the filters with new sand fresh from the river. These are all rather abnormal conditions. The Rotterdam case shows that sand filtration, although extremely efficient, has limits which it is not safe to transgress.

Prefiltration has been introduced at Zurich by Engineer Peter; at Schiedam, Halbertsma has devised the plant so as to filter the water twice. In the last few years, prefiltration through layers of gravel has been introduced at several places by M. Puech and his engineer, Chabal, with very satisfactory results. Experiments made by Mr. Bryan, the engineer to the East London Water-Works Company, have shown that such straining filters are as

efficient as the costly subsiding reservoirs much used in the English works.

Consistent with the exclusiveness in favor of spring water, French engineers were under the impression that filtration of surface water was an antiquated process, which under no consideration was to be admitted by hygiene. When filtered water was used at Paris instead of the crude Seine water, as a supplement in summer time, there was a general outcry. The constantly recurring cases of typhoid were immediately attributed to the filtered river water, or to the fact of mixing waters of varied origin. Some daily papers took up the subject. As an example of the way in which the question was treated, the surface layer of dirt was made a piece of realistic description, and the vital competition of various kinds of microbes was represented as a fight between hosts of "centipedes." A statement was published, proving "conclusively" the connection between filtered water and disease. At the merest glance it was apparent that there was no connection at all; the nearest approach to any such connection assumed an incubation of seven weeks. Nevertheless, this was accepted as gospel in many quarters; even the official "Académie de médecine" followed the lead and, on the face of such "proof," passed a unanimous vote asking for compulsory shutting off of the filtration (July 24th, 1900).

For more than ten years, Seine water purified with metallic iron, and sand-filtered had been supplied to the eastern suburbs of Paris, and typhoid at once dropped 75% in these districts; still the suburbs were charged with contaminating the city. It would then follow that if these parts of the suburbs manufactured typhoid fever, it was not for their own use, but for export only.

In the first half of the year 1901, a considerable change took place in the ideas of the leading circles at Paris. A communication of M. Chabal was specially instrumental in bringing about this result. It consisted mainly in the reproduction of the statistics of the German Imperial Board of Health, showing that the German towns supplied with sand-filtered water compared favorably with the others. This created quite a sensation, and it began to dawn upon the minds of hygienists that they might have under-estimated the process. At present, the only point with which fault can be found, is the exaggerated importance attached to the variable tem-

perature of sand-filtered water, and the occasional contention that the water must be absolutely sterile.

This latter tendency has been maintained and fostered by several inventors of chemical processes of purification. Alum and chloride of iron were already used on a large scale in some Dutch works, to clarify turbid waters or to decolorize yellow, peaty waters. The American mechanical filters have made the use of alum, or better of the pure sulphate, more practical. Of late years, a plant has been erected at Trieste, and careful experiments have been made at Alexandria (Egypt), where also permanganate of potash has been tried.

The greatest interest centers round the application of ozone for the sterilization of water. The first plant on a somewhat large scale, was erected by Baron Tindal, as an experimental station at Oudshoorn, near Leiden (Holland), and a regular plant was tried at Blankenberghe, a seaside resort near Ostend, on the Belgian coast. Ozone was made by silent discharge through cooled and dried air, then brought in contact with a fine spray of the water to be purified; but preliminary filtration was to be used, and the number of microbes and quantity of organic matter in the water, brought down first to fixed figures. Marmier and Abraham, of the Institut Pasteur at Lille, have treated the water for the town of Lille, in France. The well-known firm of Siemens and Halske has erected plants at Wiesbaden and Paderborn, and Vossmaer has worked at several places in Holland. At present, it cannot be said that the process is out of the experimental stage; but it is already known that absolute sterility is exceedingly difficult to obtain. And it is noteworthy that the hygienic requirements which some of these inventors claimed for a good supply, have suffered an attenuation, proportionate to what their schemes could accomplish.

Several processes of chemical purification were tried along the Belgian coast. All surface waters are of very bad quality; underground waters through deep borings are insufficient in quality and strongly mineralized. The sanitary situation was far from satisfactory. Special attention is paid in Belgium to all that concerns the seaside resorts, and the Government took the matter in hand. Some of the experiments have been costly failures; but the Lawrence experiments have also been financially a very bad

affair for the State of Massachusetts. Such work must not be regarded in that light; it is a scientific enquiry, the result of which is profitable to all municipalities, and it is only just that the State should bear the cost, which would be too great a burden for any single municipality. If one of the processes of purification can be shown to work well, the result is a highly valuable one; if, on the contrary, a system falls short, the ground is cleared, and further useless expenditure is avoided. In both cases, the result is worth knowing, and, in the end, the expenditure is a good investment.

Besides the experiments with ozone by Baron Tindal, at Blankenberghe, already mentioned, an oxygenated compound of chlorine has been tried at Ostend. By the reaction of concentrated sulphuric acid on chlorate of potash, there is evolved a gas, $Cl_2 O_4$, or $Cl O_2$. Air charged with these vapors was brought in contact with the water; the vapors decomposed quickly, evolving a small amount of free chlorine, which it was contended would suffice to sterilize the water, and would disappear completely in a short time. In order to hasten the disappearance of the free chlorine, the water was passed through coke. It was also contended that when the water, after the action of the gas, showed for a short time a positive reaction with starch iodide, complete sterilization was assured. The process was called "the peroxide of chlorine process." The preparation of the gas is not free from danger; the solid salt was added in small quantities to the strong acid. Although an official committee reported favorably on the process, the experiment was discontinued in 1901.

Since July, 1902, a small plant has been working at Middelkerke (south of Ostend), to purify 150 cu. m., or 40 000 gal. a day. Two solutions, one of chloride of lime and one of chloride of iron, are mixed with the water; oxide of iron is precipitated, and oxygenated compounds of chlorine, where hypochlorous acid predominates, are formed. The rather complicated chemical theory of the process has been very ably worked out by the inventor, M. Duyk, Chemist to the Ministry of Finance at Brussels. The results have been very satisfactory, the water is bright and palatable. Recent experiments at Paris on the spring water of the Vanne show that with 0.5 part per million of chloride of lime and 8 parts of chloride of iron, at the outlet of the straining filter, the 250 germs of the raw water

are reduced to 13 per cu. cm., and that the *coli* is absent. With larger quantities of reagent, complete sterilization can be obtained. The process is called "ferrochlore."

Summing up, we find as noteworthy facts during the past decade:

1.—Confirmation by the Hamburg cholera of August, 1892, of the danger of surface waters;

2.—Danger of departing from the sound principle of long decantation with impounding reservoirs (cases of Remscheid and Verviers);

3.—Danger of waters from fissured limestones and insufficiently protected springs (Paris, Maidstone), recognized in France;

4.—Replacing of surface-filtered waters, by underground waters, aerated to precipitate iron (Germany and Holland);

5.—Perfecting sand filtration through scientific study; practical rules of Koch;

6.—Recognition of the efficiency of sand filtration in France;

7.—Danger of overtaxing sand filters, especially in winter (Rotterdam);

8.—Introduction of American Mechanical Filters;

9.—Attempts at sterilization by chemical processes: ozone, "peroxide of chlorine," "ferrochlore."

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 50.

PURIFICATION OF WATER FOR DOMESTIC USE.

INVESTIGATIONS FOR GROUND-WATER SUPPLIES.

By J. M. K. Pennink.*

Introduction.

The investigations of the sources of ground-water supplies, on little islands in the ocean, or on the seacoast, during the last decade, have brought out very interesting particulars.

It is therefore thought that the publication of the results of investigation of the sources of the Amsterdam dune-water supply, will be important for those who have to do with similar problems.

Plan of Investigation.

In the investigation of the dunes, principally situated within the territory of the sources of the Amsterdam Dune Water-Works, an attempt has been made to investigate the dunes in two directions: in the direction of their longitudinal axis and across them. (See Fig. 1.)

* Director of the Amsterdam Water Supply.

The axis in a W. N. W. to E. S. E. direction runs through the "Nieuw Leiduin" pumping station, and is perpendicular to the main direction of the line of "strand poles." The axis in a N. N. E. to S. S. W. direction runs through the junction of the Barnaert, Schuster and Zwarteveld Canals, and is parallel with the line of "strand poles." The intersection of these axes has been considered as the origin from which the distances of the borings are measured parallel with one of the axes. For simplicity, these are expressed as West, East, North or South (more exactly, W. N. W., E. S. E., N. N. E. or S. S. W.). W. 1 000 means a boring on the cross-section 1 000 m. west of the origin, on the W. N. W. to E. S. E. axis, etc.

The investigation, of the cross-section running principally in a west to east direction, is completed. The investigation of the longitudinal section is not yet finished.

Primarily, the cross-section has been investigated in connection with the theory advanced with regard to the hydrological condition of the ground at a depth of from 100 to 200 m. below Amsterdam datum.

With regard to the remainder of the water the same conditions will be found all through the longitudinal section, whereas, in the cross-section, for short distances, other phenomena will be met.

In this hydrological theory the sea forms the origin and the Haarlemmermeer polder the terminus, and the cross-section has been investigated between these two points, commencing with a deep boring at "strand pole" No. 69 and terminating with a deep boring at the "de Cruquius" drainage pumping station of the Haarlemmermeer polder, thus covering a distance of 8 800 m. in a direction from west to east.

At regular intervals between the two termini a greater or less number of deep borings have been made.

The depth of these borings is from 100 to 160 m., and they average 1 500 m. apart. Between the deep borings a number of shallower borings have been made. Generally, between each two deep borings there is one shallow boring to a depth of about 30 m.

The following is a brief statement of the results obtained in the investigation of these borings:

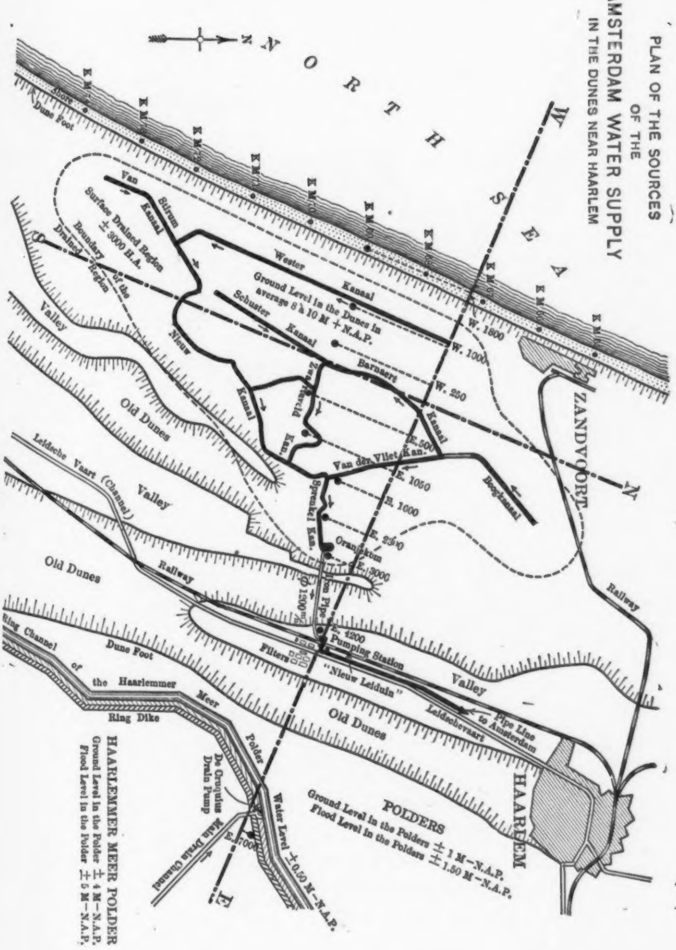
PLAN OF THE SOURCES
OF THE
AMSTERDAM WATER SUPPLY
IN THE DUNES NEAR HAARLEM
NORTH SEA
W
N
E
Shore
Dune Foot
Van Stirum Kanaal
Surface Drained Region
± 3000 H.A.
Boundary of the Drained Region
Wester Kanaal
Ground Level in the Dunes in average 8 à 10 M + N.A.P.
Schuster Kanaal
Nieuw Kanaal
Barnaart Kanaal
Van der Vliet Kan.
Boogkanaal
Sprenkel Kan.
Oranjekom
Iron Pipe
W. 1500
W. 1000
W. 250
E. 500
E. 1050
E. 1600
E. 2300
E. 3000
E. 4200
E. 7000
ZANDVOORT
Railway
Valley
Old Dunes
Leidsche Vaart (Channel)
Pumping Station
Filters
"Nieuw Leiduin"
Pipe Line to Amsterdam
Leidschevaart
HAARLEM
POLDERS
Ground Level in the Polders ± 1 M−N.A.P.
Flood Level in the Polders ± 1.50 M−N.A.P.
Ring Channel of the Haarlemmer Meer Polder
Ring Dike
De Cruquius Drain Pump
Main Drain Channel
Water Level ± 0.50 M−N.A.P.
HAARLEMMER MEER POLDER
Ground Level in the Polder ± 4 M−N.A.P.
Flood Level in the Polder ± 5 M−N.A.P.

FIG. 1.

Geological Particulars.

Fig. 2 is a geological section from the North Sea, over the dunes, into the Haarlemmermeer polder.

A study of the various borings discloses the following principal formation:

A.—Alluvium: from the surface to an average depth of about 23 m.

B.—Diluvium: from about 23 m. to deeper than about 150 m.

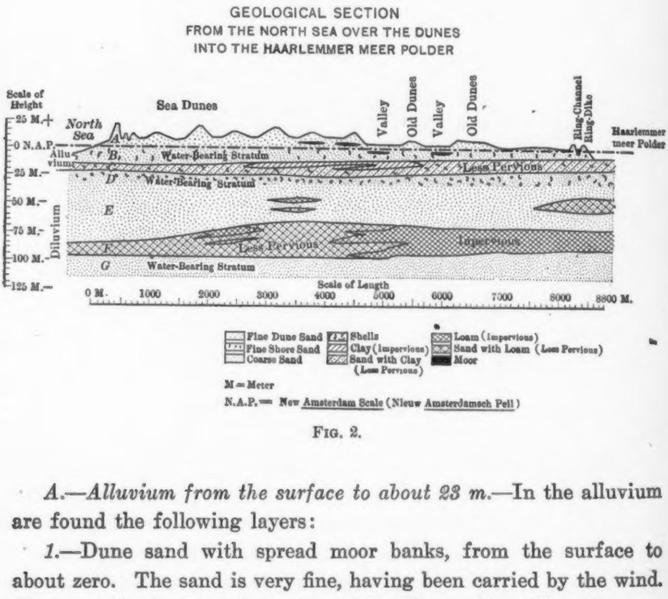

Fig. 2.

A.—Alluvium from the surface to about 23 m.—In the alluvium are found the following layers:

1.—Dune sand with spread moor banks, from the surface to about zero. The sand is very fine, having been carried by the wind. The moor banks have been formed locally in the valleys between the dunes, and, later, dusted over by dune sand. The average granular size and nature of this sand may be expressed by the following figures: The effective size = 10% finer than 0.182 mm.

The uniformity coefficient =

$$\frac{60\ \%\text{ finer than } 0.282\text{ mm.}}{10\ \%\text{ finer than } 0.182\text{ mm.}} = 1.55.$$

2.—Shore sand with spread moor banks.

Under the yellow dune sand is found the blue-gray shore sand mixed with a great many sea shells.

This formation commences at about zero and runs through to about 13 m. The average granular size and nature of this sand may be expressed by the following figures:

The effective size = 10% finer than 0.175 mm.

The uniformity-coefficient =

$$\frac{60\% \text{ finer than } 0.282 \text{ mm.}}{10\% \text{ finer than } 0.175 \text{ mm.}} = 1.61.$$

3.—Fine sand mixed with clay, and "clay lenses," from about 13 m. to about 23 m.

This formation offers great resistance, with regard to water-passing capacity, compared with the dune sand and shore sand. The clay lenses, which appear locally, offer the greatest resistance to the passage of the water in a vertical direction.

The average granular size and nature of the blue-gray clay, may be expressed by the following figures:

The effective size = 10 % finer than < 0.01 mm.

The uniformity coefficient =

$$\frac{60\% \text{ finer than } 0.083 \text{ mm.}}{10\% \text{ finer than} < 0.01 \text{ mm.}} = > 8.3.$$

B.—Diluvium from about 23 m. to deeper than about 150 m.

As far as the deep borings go, the following layers may be observed in the diluvium:

1.—Rather coarse sands, with fine gravel; sometimes pebbles and many oyster shells; from about 23 m. to about 30 m.

The average granular size and nature of this sand may be expressed by the following figures:

The effective size = 10% finer than 0.187 mm.

The uniformity coefficient =

$$\frac{60\% \text{ finer than } 0.401 \text{ mm.}}{10\% \text{ finer than } 0.187 \text{ mm.}} = 2.14.$$

2.—Loamy fine sands with spread loam lenses. This formation runs from about 30 m. to an average depth of 75 m.

The average granular size and nature of this sand may be expressed by the following figures:

The effective size = 10% finer than 0.162 mm.

The uniformity coefficient =

$$\frac{60\% \text{ finer than } 0.331 \text{ mm.}}{10\% \text{ finer than } 0.162 \text{ mm.}} = 2.04.$$

3.—Loamy fine sand and loam layers, from about 75 m. to about 100 m.

The average granular size and nature of this loam may be expressed by the following figures:

The effective size = 10 % finer than < 0.01 mm.

The uniformity coefficient =

$$\frac{60\% \text{ finer than } 0.056 \text{ mm.}}{10\% \text{ finer than } < 0.01 \text{ mm.}} = > 5.6.$$

4.—Coarse sands with gravel, from about 100 m. to deeper than 150 m.

The average granular size and nature of this sand may be expressed by the following figures:

The effective size = 10% finer than 0.212 mm.

The uniformity coefficient =

$$\frac{60\% \text{ finer than } 0.472 \text{ mm.}}{10\% \text{ finer than } 0.212 \text{ mm.}} = 2.22.$$

Hydrological Particulars.

The hydrological particulars indicated by Fig. 3, which represents the hydrological section from the North Sea over the dunes into the Haarlemmermeer polder, are as follows:

The geological section shows two strata having a great filtering resistance, in vertical, as well as in horizontal, direction, and three water-bearing strata.

Imagine, for a moment, that the water of the North Sea covered the low lands of Holland, then, with regard to the head of the salt water in the deeper strata, west as well as east, the same conditions would appear.

Further, if there were more porous strata instead of the less pervious ones, the problem would be made most simple, with regard to the balance of the water at the various depths.

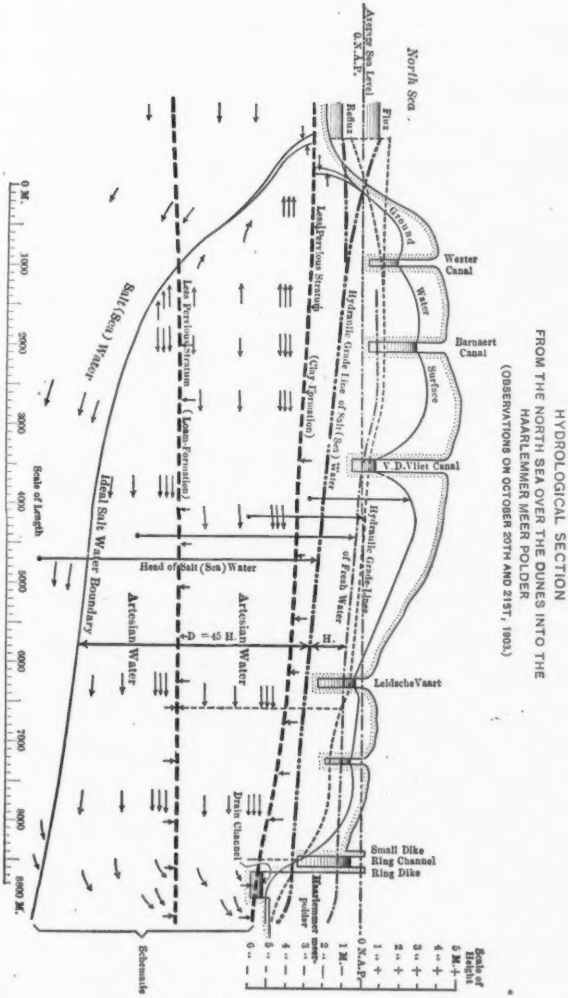
HYDROLOGICAL SECTION
FROM THE NORTH SEA OVER THE DUNES INTO THE
HAARLEMMER MEER POLDER
(OBSERVATIONS ON OCTOBER 20TH AND 21ST, 1903.)
North Sea.
Average Sea Level
0.N.A.P.
Flux
Reflux
Ground
Water
Surface
Wester Canal
Barnaert Canal
V.D.Vliet Canal
LeidscheVaart
Small Dike
Ring Channel
Ring Dike
Haarlemmer meer-polder
Hydraulic Grade Line of Salt (Sea) Water
Hydraulic Grade Lines of Fresh Water
Less Pervious Stratum
(Clay Formation)
Less Pervious Stratum
(Loam-Formation)
Salt (Sea) Water
Head of Salt (Sea) Water
Artesian Water
Artesian Water
D = 45 H.
H.
Ideal Salt Water Boundary
Drain Channel
Scale of Length
0 M.
1000
2000
3000
4000
5000
6000
7000
8000
8900 M.
Scale of Height
5 M.+
4 " +
3 " +
2 " +
1 " +
0 N.A.P.
1 M.—
2 " —
3 " —
4 " —
5 " —
6 " —
Schematic

FIG. 3.

For such a simple case, the little Isle of Borkum may be taken as an example, and, just as it has been proved there, the surface of the ground-water in the dunes will have a curved form with the top in the midst of the dunes, whereas from the top the ground-water surface slopes symmetrically to both sides.

In the same manner, the high ground-water level would also cause the salt water to be pressed away. In this most simple case, for the Isle of Borkum, as investigations by Herzberg have shown, a supply of fresh water will be formed under the average sea level.

An examination of Fig. 3 makes it clear that the highest ground-water level appears in the midst of the dunes. A great quantity of this water (percolated rain-water) flows away in a horizontal direction into the drainage channels of the Amsterdam dune-water supply. Other quantities, also, try to flow away into the porous strata beneath the clay and loam formations.

It has been observed that, in the midst of the dunes, the ordinary ground-water level is above the hydraulic grade line of the artesian water beneath the clay formation. On account of this loss of head the dune water must also flow away in a vertical direction to the coarser diluvial sand strata.

Beneath the fresh water in the diluvial sand strata first there is a zone of brackish water containing a great and increasing quantity of chlorine: from 100 to 15 000 or 17 000 mg. per liter.

The ideal salt-water boundary is indicated by the line of about 10 000 mg. of chlorine per liter; if the chlorine, with its combinations of other substances above that line, is mixed with the part below that line, the average chlorine content of all the water beneath becomes 16 000 to 17 000 mg. per liter, with a specific gravity of about $1\frac{1}{45}$.*

If, in the same vertical, the fresh water floats on the salt water, for every meter by which the head of the fresh water is higher than the head of the salt water the latter will be pushed away about 45 m. deep beneath the head of the salt water, and thus about 46 m. beneath the head of the fresh water. (See Fig. 3.)

The various hydraulic grade lines which have been constructed by means of the observations made during the 24 hours on October 20th and 21st, 1903, will now be described successively.

* North Sea water has about 16 000 to 17 000 mg. of chlorine per liter.

These hydraulic grade lines are:

A.—The salt-water hydraulic grade line,

B.—The fresh-water hydraulic grade lines, and

C.—Surface line of the dune water (the ordinary ground-water level).

A.—The Salt-Water Hydraulic Grade Line.—The average sea level at Ymuiden was 0.17 m. The average head of salt water in the Cruquius boring was 3.78 m.; the total loss of head was 3.61 m.

The flood level of the main drainage canal of the Haarlemmermeer polder was 5.46 m.; thus the salt water from the depth, with its greater specific gravity, then might have risen 1.68 m. above the polder-water level.

Thus the sea water flows from the North Sea in the lower coarse sand strata toward the low lands of Holland, and takes an upward course beneath these polders.*

The highest flow near the old sea sluice at Ymuiden was 0.94 m., and the lowest back flow 1.07 m., an amplitude of 2.01 m.

In the Westerkanaal boring, the head of the salt water varied between 0.89 and 1.11 m. (from tidal influence), thus showing an amplitude of 0.22 m., whereas the average head amounted to 0.98 m.

From the Westerkanaal boring to the Cruquius boring, also over a length of 8 000 m. taken on the west to east axis, the loss of head of the salt (sea) water amounted to 3.78 — 0.98 m. = 2.80 m., an average slope of about $\frac{1}{2\,900}$.

This salt-water hydraulic grade line is the basis for the general condition of balance, and for the depth at which fresh water will be found.

B.—The Fresh-Water Hydraulic Grade Lines of the Water in the Diluvial Sand Strata.—The highest head of the water in the diluvial sand strata was gauged in boring W 250 and this averaged 1.07 m.; 750 m. westward, this head amounted to 1.02 m.; 750 m. eastward of boring W 250, this head amounted to 1 m.

It is likely that the highest point of the hydraulic grade line of the fresh water, which floats immediately on the salt water, will be found at W 250.

Then, from this point, beneath the clay and loam formation,

* The drain water of the polders in Holland is generally brackish.

water is flowing westward to the North Sea and eastward to the Haarlemmermeer polder.

What will be the slope at which loss of fresh water to the sea takes place?

This slope, of course, will change in accordance with the tides.

It is seen that in W 250, beneath the clay formation, tidal influence is still slightly noticeable; the highest head was 1.10 m., the lowest head 1.04 m., and the average head 1.07 m.

Westward of W 250 the tidal influence of the North Sea becomes more and more noticeable on the head of the water beneath the clay formation.

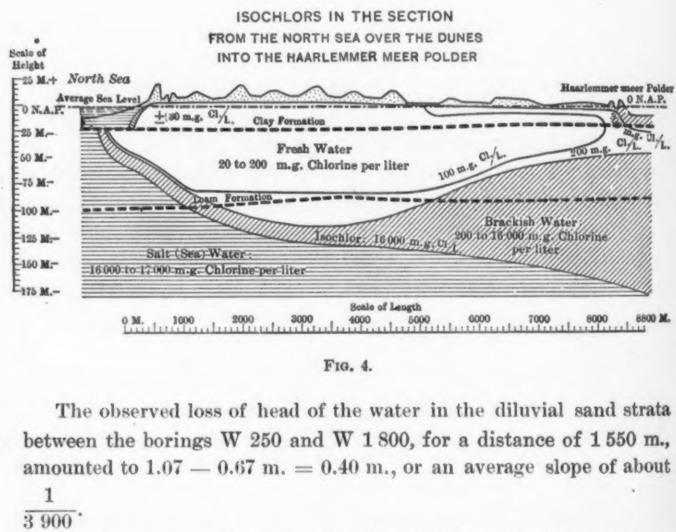

FIG. 4.

The observed loss of head of the water in the diluvial sand strata between the borings W 250 and W 1 800, for a distance of 1 550 m., amounted to 1.07 — 0.67 m. = 0.40 m., or an average slope of about $\frac{1}{3\,900}$.

The fresh water between the clay and loam formations flows toward the Haarlemmermeer polder with an average slope of about $\frac{1}{1\,500}$.

It may still be observed that the fresh water beneath the impervious loam layer flows away to the Haarlemmermeer polder with another hydraulic grade line.

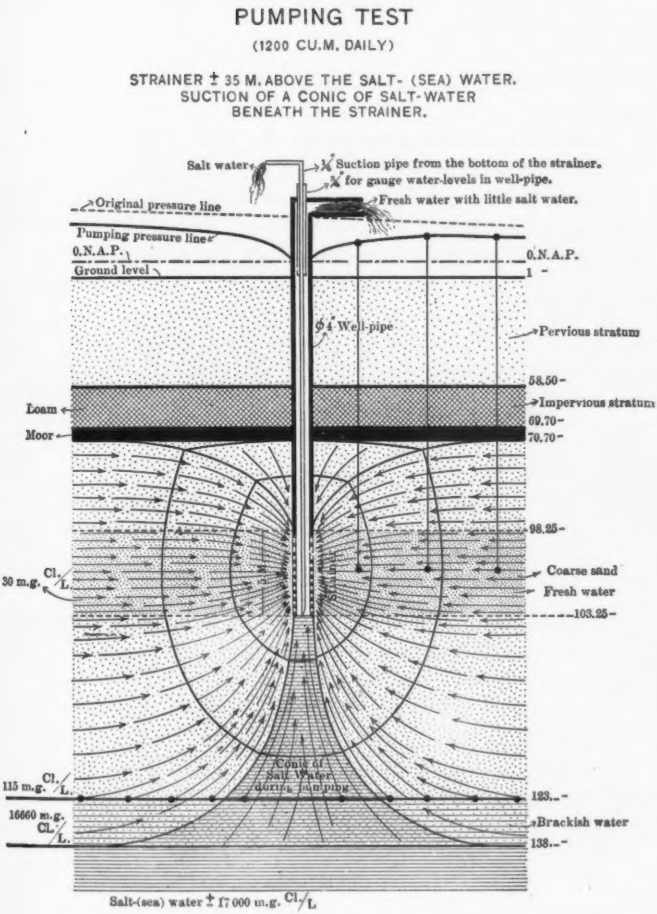
PUMPING TEST
(1200 CU.M. DAILY)
STRAINER ± 35 M. ABOVE THE SALT- (SEA) WATER.
SUCTION OF A CONIC OF SALT-WATER
BENEATH THE STRAINER.
Salt water
¼" Suction pipe from the bottom of the strainer.
⅜" for gauge water-levels in well-pipe.
Fresh water with little salt water.
Original pressure line
Pumping pressure line
0.N.A.P.
0.N.A.P.
Ground level
1 -
ϕ 4" Well-pipe
Pervious stratum
58.50 -
Loam
Impervious stratum
69.70 -
Moor
70.70 -
98.25 -
Strainer
5 M.
30 m.g. Cl./L.
Coarse sand
Fresh water
103.25 -
Conic of Salt Water during pumping
115 m.g. Cl./L.
123.. -
16660 m.g. Cl./L.
Brackish water
138.. -
Salt-(sea) water ± 17000 m.g. Cl./L

FIG. 5.

In the Cruquius boring the head of the fresh water beneath the loam layer is 1.02 m.

At a distance of 7 250 m. the total loss of head is also 2.09 m., or an average slope of about $\frac{1}{3\,500}$.

Up to June, 1904, the observations give the same results as are described for October 20th and 21st, 1903.

Isochlors for the section from the North Sea over the dunes into the Haarlemmermeer polder are shown in Fig. 4.

In the pumping test, 1 200 cu. m. were pumped daily. The strainer was ± 35 m. above the salt (sea) water. Fig. 5 shows a section of the cone of salt water beneath the strainer.

The pumping test began on October 10th, 1903. The chlorine content in the pumped water then amounted to 30 mg. per liter. The quantities of chlorine contained in the water pumped, on the dates given, were as follows:

Date.		Chlorine per liter.
November	1st, 1903	33 mg.
"	15th, 1903	40 "
December	1st, 1903	52 "
"	15th, 1903	64 "
January	1st, 1904	81 "
"	15th, 1904	93 "
February	1st, 1904	106 "

On February 1st, 1904, the water which flowed into the strainer, near the bottom, was also examined, and was found to contain 3 560 mg. of chloride per liter.

For water supplies which have their sources on little islands in to the bottom of the strainer.

Thus it has been demonstrated that the salt water was sucked into the strainer, by disturbing the balance.

Afterward, the results shown in Table 7 were found.

Conclusion.

For water supplies which have their sources on little islands in the ocean, or on coast lands, care must be taken to investigate the hydro-geological conditions of the sea water in the ground, so that by taking the water, the balance is not disturbed in such a way that salt water may reach the drainage works.

TABLE 7.

Date, 1904.	Chlorine content in the water from the 4-in. well pipe.	Chlorine content in the water sucked from the bottom of the strainer with ¼-in. pipe.
February 1	106	3 562
" 2	111	3 616
" 3	107	......
" 4	107	3 810
" 5	108	......
" 6	110	......
" 7	109	......
" 8	110	......
" 9	111	3 881
" 10	111	......
" 11	111	......
" 12	113	4 023
" 13	114	4 129
" 14	113	......
" 15	114	4 183
" 16	115	4 165
" 17	115	4 200
" 18	116	4 219
" 19	116	4 289
" 20	118	4 271
" 21	116	......
" 22	120	4 289
" 23	121	4 289
" 24	122	4 360
" 25	123	4 377
" 26	123	4 448
" 27	126	4 467
" 28	128	......
" 29	126	4 513

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 51.

PURIFICATION OF WATER FOR DOMESTIC USE.

FRENCH PRACTICE.

By M. Bechmann.*

Translated from the French by

Allen Hazen, M. Am. Soc. C. E.

Treatment of Municipal Supplies.—A sufficiently large number of cities in France (57 with over 5 000 inhabitants each, according to the "Annuaire des Distributions d'Eau," 1st edition, 1904) continue to use the system of filter galleries in the alluvial deposits near the banks of watercourses. This system was put in practice in 1825 by d'Aubuisson, upon the banks of the Garonne, for the supply of the City of Toulouse. Later, Aristide Dumont used it for the supplies of Lyons and Nîmes. The system came to be known as "natural filtration," notwithstanding the fact that in reality the proportion of water coming through the gravel from the river was often relatively small, being mixed with a large quantity of water coming through the ground toward the river. When the filtration is really effective, the silting up of the filtering surfaces diminishes the supply and necessitates successive and frequent extensions of

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the galleries. Dr. Imbeaux, *Ingénieur des Ponts et Chaussées,* and Director of Municipal Works of the City of Nancy, has substituted recently for this practice an ingenious method of doubling the amount obtainable from the filter gallery established for the city at Messein, upon one of the banks of the Moselle. He has built an open canal through the gravel, and conducts through it the river water parallel with the gallery and on the opposite side of it from the bank of the river. This has the effect of making both sides of the filter gallery equally effective. This method has been entirely successful, and recalls the system originated in Sweden by Richert, which depends upon carrying the surface waters to be used over a naturally porous ground, from which the water is taken after purification. Of somewhat the same type was a project studied in 1898 for a new and additional water supply for Paris. This contemplated taking 5 cu. m. of ground water per sec. (114 000 000 gal. daily) from the Valley of Orleans. The water in this formation also finds the Loiret, which appears to be almost exclusively supplied by seepages from the Loire through the calcareous formation of Beauce.

M. Lefort, *Ingénieur des Ponts et Chaussées,* engaged in improving the water supply of the city of Nantes, proposed, a dozen years ago, to secure artificially the most favorable conditions for natural filtration, by creating at many places in the bed of the Loire, a little above the city, islets of fine sand, in the middle of which were established wells, provided with suitable works for their control, from which water was to be taken. Notwithstanding a satisfactory trial of this process, it was not applied. It was the same with the process devised by M. Janet, Engineer of Mines, in connection with the studies for additional water supply for the City of Paris. The suggested procedure was to pump the waters of the Seine and of the Oise to a considerable height, and to spread them on the summits of sandy hills, which exist at many points about Paris (Montmorency, Hautie, Fontainebleau, etc.), and to collect them again at the base of these hills at the bottom of the Fontainebleau sands, which were to play the part of a natural filter of great thickness (50 m. and more).

Vertical filtration through artificial beds of fine sand by the system used at London since 1829, and which has been followed throughout the whole world, has remained until a very recent date,

almost entirely without application worthy of the name in France. Ten years ago one could only cite the City of Libourne as supplied by a filtering establishment upon a rational plan. The situation has been modified considerably in the last years. The "Annuaire des Distributions d'Eau" now mentions 61 French cities of more than 5 000 inhabitants each which use filtered water. The initiative in this movement was taken by the General Water Company, which installed an experimental water plant at its works at Boulogne-sur-Seine according to the Anderson process which had been previously applied in Antwerp. This process consisted in the treatment of water by metallic iron, in turning drums called revolvers, and subsequent filtration through fine sand. In 1894 this company made arrangements for the systematic application of this process to 46 cities in the suburbs of Paris, which had been supplied up to that time with raw water from the Seine and the Marne. Two plants were established, one at Choisy-le-Roi and one at Neuilly-sur-Marne, which permitted the company to supply water, purified and filtered by the Anderson process, in all the communes of the Department of the Seine, where it had the concession. There immediately followed a considerable reduction in the typhoid fever mortality.

The City of Paris, which had nominally been supplied with spring water only for domestic purposes, in 1894 considered the matter of purification of surface waters, and since then two sand filter plants have been established, one at Saint-Maur (1895-96), and one at Ivry (1899-1900), capable of treating respectively 25 000 cu. m. (5 600 000 gal.) of Marne water, and 35 000 cu. m. (9 250 000 gal.) of Seine water per day. These plants are intended to furnish for domestic uses such water as may be necessary to make up temporary deficiencies in the supply of spring water.

It was in the second of these establishments that the first application was made of the process of scrubbing by systematic preliminary filtration through layers of gravel of decreasing size, invented by M. Puech. This process has shown itself superior to the limited sedimentation previously used at Saint-Maur, and it has subsequently found more than one application in France and other lands. It is now projected to double the plant at Ivry. The same system, that is, filtration through fine sand at the rate of 0.1 m. per hour (2 570 000 gal. per acre daily), with preliminary filtration by five

passages through Puech scrubbers, is in course of installation at Suresnes, to treat the water distributed to eight villages of the Department of the Seine by the Suburban Water Company.

Rapid filters, with or without chemical reagents, have not received any application, worthy of notice, in the municipal works of France. The process of Maignen, with "carbo-calcis" with filtration through asbestos cloth, which was tried at Saint-Maur in 1896, did not succeed in meeting the requirements of the contract with the City of Paris, and it was no more successful at Cherbourg, where it was applied to the purification of the water of the Divette. On the other hand, reasonably satisfactory results were obtained in 1903 by M. Howatson at the Montsouris reservoir at Paris, in a practical trial of the process called "ferrochlore." This process was invented in Belgium by M. Duyk, and consists in the application of two chemicals, hypochlorite of lime (bleaching powder) and ferric chloride, followed by a rapid filtration through quartz sand. The effluent from this treatment was almost sterile and the traces of chlorine, which it sometimes contained, on leaving the filter seemed to disappear spontaneously in a few hours.

A single city, Parthenay, 7 500 inhabitants, has sterilized its water by heat, treating 3 cu. m. (790 gal.) per hour, with two Rouart sterilizers. This process has received many applications in isolated establishments, such as barracks, hospitals, etc.

Purification by ozone was proposed in France in 1895 by Baron Tindal. He had applied it before at Oudshoorn in Holland, and he made a demonstration of it in the same year at the International Exposition of Hygiene at the Champ de Mars in Paris. In 1896 he was authorized by the City of Paris to make a trial on a large scale, 5 cu. m. (1 320 gal.) per hour, at the filtration works at Saint-Maur, but in the trials, the attempts, three times renewed, to sterilize filtered Marne water failed to meet the required conditions. M. de Frise afterward acquired the process and material of Baron Tindal, secured patents for the perfection of the process, and is undertaking a new trial with the Marne water raw, except for a rapid preliminary scrubbing. At Lille, MM. Marmier and Abraham conducted industrial experiments covering several months in 1898 and 1899, upon the ground-water of Emmerin, which is distributed in that city. They succeeded in destroying all microbes, pathogenic

and saprophytic, with the exception of *Bacillus subtilis*. Their process received a high award at the Universal Exposition of 1900. Nevertheless it has not found practical application. The process of M. Otto, in which the apparatus for the production of ozone is entirely metallic to the exclusion of all glass, has been made the subject of many experiments and of projected applications, notably at Suresnes, and the City of Nice is on the point of constructing an apparatus for treating its water upon this system.

Small Filters for Isolated Dwellings.—The Chamberland filter of unglazed porcelain remains the most extensively used for this purpose. Its efficiency is not doubtful when the bougie is frequently cleaned and sterilized. M. Vincent showed in 1897 that the most certain practical procedure of accomplishing this is baking at dry heat of 280 to 300° cent., maintained for half an hour. The small yield of the filters, even under a considerable pressure, makes it necessary to group the units in batteries when it is necessary to supply more than a very little water. The aerating filter of Mallié, which operates with or without pressure, and in which the filtering element is also a bougie, but of Garros amianth porcelain. The Howatson filter with a bougie of infusorial earth is also operated under pressure, and is grouped in batteries. These filters give equally good results but have received less numerous applications. The Maignen Filter Company continues to exploit its system of mechanical and chemical filtration through sacks of asbestos cloth, filled with "carbo-calcis" mixed with charcoal and chalk, of which the charcoal is manifestly the most active agent. This system has retained a certain vogue, notwithstanding the failures which have attended its application on a large scale. Apparatus is also constructed where the single filtering elements of the batteries are formed of cellulose. These filtering elements may be easily and cheaply renewed, which is an advantage. They are formed sometimes by a plate sufficiently thick and fastened in a wooden frame (Grandjean filters and those of the Pasteurized Filter Company), sometimes by the use of simple leaves of paper applied one above another and placed over a disc of porous carbon (Eden filters). They seem to arrest the microbes quite as well as porcelain, but their yield diminishes very rapidly, and it is necessary to replace the cellulose almost every day.

MM. Girard and Bordas, Director and Assistant Director of the Laboratory of the Prefect of Police at Paris, have studied the use of permanganate of lime, which has an action similar to that of permanganate of potash, but has the advantage of producing only insoluble products which are easily separated after reaction. The filters of Lutèce and Lapeyrère are constructed upon this principle.

In large isolated establishments there is a tendency to use sterilization by heat. The apparatus for doing this has been greatly improved in recent years. There are several makers of this apparatus, MM. Rouart, Geneste and Herscher were the first to carry water to 120° cent. under pressure, and cool it again in a closed space, holding the dissolved gases so that it does not lose its agreeable qualities for drinking. This apparatus consists of a heater. followed by a regenerative apparatus where the hot sterilized water circulates through a coil, about which circulates the cold water to be sterilized. Two or even three coils are sometimes used, and the effluent goes through a clarifier of crushed quartz. The particulars of the arrangement differ according to circumstances. Gas burners are often used in cities, while the apparatus is mounted on wheels for temporary installations (camps, army maneuvers, fairs, etc.). The Vaillard and Desmaroux and the Houdard Eyrot and Grangé sterilizers are based upon the same principle, but differ in arrangements of parts. They are equally used. In the first, the water to be purified passes at the outset through a clarifying filter. It then passes through a pressure regulator and a temperature regulator, afterward through two compartments called recuperators, and finally to a steam chamber, and then into the coils formed of annular spaces, one above another, and placed in the heater, so that the water goes back through nearly the same course, giving its heat to the water coming in the other direction while it cools itself before leaving. In the second, the generative apparatus is tubular, as is also the steam chamber, and the water is circulated by a pump, while regulators allow the desired yield and heat to be obtained. Until recently the process of sterilizing by heat has been confined to large establishments, but now an apparatus is offered (Lepage) in which the elements are so small that it is operated by an alcohol lamp.

Purification of Water for Industrial Purposes.—For industrial

purposes one is contented generally with clarification or a sort of scrubbing which can be obtained in most cases by mechanical means. The appliances used for this purpose in factories in France are usually rapid filters, in which the filtering element is generally a sand layer, or often gravel or a crushed quartz.

Such, for example, is the Desrumeaux filter, consisting of a vertical metallic cylinder, on the bottom of which is a frame of perforated sheet iron, resting upon a steel blocking. The frame is designed to receive the various layers of sand and gravel, in decreasing sizes, above which is the water to be purified. The water goes through from top to bottom and escapes below. After a time the pores in the filtering material are filled. With the increasing resistance the water rises in the cylinder above the sand until it finally lifts a float which operates valves and causes the filter to be washed by a reverse current of filtered water. The filtering material is agitated at the same time by a disc carrying teeth, moved by hand until the washing is complete. In the Howatson filter the general arrangement is the same, except for the float which puts the washing in operation automatically, and the sand is sometimes replaced by a special compound, Polarite, a mixture of magnitite and silica, with several other bodies, and which has the property of retaining and concentrating the oxygen of the air, which afterward exerts an oxidizing action upon the organic matters. The material is revivified by a simple exposure to the air at intervals. The apparatus of Dervaux and Wilson is based upon the same principle and has similar arrangements, but it is provided with a siphon which starts to operate when the washing is necessary, and which determines the reversal of the current, and the apparatus for returning the filter to its normal operation after a certain amount has been passed through it. In the apparatus of Delhotel and Moride there is also the same general arrangement, but to avoid the frequent washings and the interruptions in the supply which accompany them, wash water is incessantly introduced through jets into the upper layer of the filtering material.

The softening of water to prevent the formation of boiler scale by precipitating the earthy salts is not applied in France in so general a manner as in England. It is used somewhat particularly in the North, and in those quarters of Paris where industrial

establishments receive very hard water from the Canal de l'Ourcq. The apparatus used generally consists of filters similar to those which have been described, notably the filters of Desrumeaux, but with the addition to the raw water of certain reagents in suitable doses. These reagents consist habitually of milk of lime and a solution of soda-ash.

TRANSACTIONS

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DISCUSSION ON

PURIFICATION OF WATER FOR DOMESTIC USE.

By Messrs. Andrew Howatson, George C. Whipple, Edwin O. Jordan, Edmund B. Weston, L. J. Le Conte, J. P. A. Maignen, J. N. Chester, Robert Spurr Weston, Gardner S. Williams, Rudolph Hering, F. L. Fuller, E. E. Wall, John F. Wixford, George W. Fuller, Allen Hazen, Dr. Adolph Kemna and M. Bechmann.

Andrew Howatson, Assoc. M. Inst. C. E., Paris, France. (By letter.)—Mr. Hazen has treated the subject in a masterly manner, showing that he is thoroughly conversant with all the details of water filtration and purification. Mr. Howatson.

The only point on which he seems to hesitate is coagulation. He gives alum, sulphate of alumina and copperas as suitable substances for the purpose. The writer's experience proves, however, that they are quite incapable of sufficiently purifying a contaminated water for domestic consumption. No doubt they aid the clarification and entangle a certain number of bacteria, but they do not kill them. If the filtering film formed on the surface of the sand is examined, it will be found teeming with bacteria of all sorts, and in this struggle for life the dangerous ones are supposed to be killed, but there is no certainty as to this, and typhoid and other germs are continually found in the filtered water.

Experiments with all known coagulants have been made at Ostend, where a mechanical filtering plant was fitted up to treat 2 500 000 gal. of water per day, drawn from the canal. This water

Mr. Howatson. is highly contaminated with sewage and the above-named coagulants gave very poor results. Recourse was then had to peroxide of chlorine, which sterilised the water, and, in conjunction with sulphate of alumina, produced a tolerably clear water, but the pronounced yellow tinge remained as well as a fishy smell and taste.

Mr. Duyk, who is a member of the Government Commission, proposed the use of perchloride of iron and chloride of lime. Having in hand a filtering plant for Middelkerke, near Ostend, this process was applied, which the originator called Ferrochlore. This process used with the same water as at Ostend gave absolute satisfaction, so much so that after two years' trial the Belgian Government ordered another plant and decided finally to adopt the process.

Ferrochlore is added to the water before filtration. Its composition is free oxygen, oxides of chlorine and hydrate oxide of iron.

The mechanical filters are constructed so that there is a head of 10 ft. on the filtering surface, thus giving sufficient time for the chemical reactions to take place and for the destruction of all bacterial life before the water reaches the filtering medium.

The free oxygen and oxides of chlorine act on the bacterial life and organic matters. The hydrate of iron is the coagulant; it entangles the dead bacteria and the suspended organic matters and deposits them on the surface of the sand, forming a gelatinous film, which is essential to good filtration. This film is sterile and composed of inert matter, while in other processes the film formed contains myriads of bacteria.

The advantages which Ferrochlore possesses over all other substances is that it is a powerful steriliser, and, at the same time, a coagulant. It acts quite independently of the composition of the water to be treated.

After treatment the water is beautifully clear and free from taste or smell.

The cost of the Ferrochlore treatment ranges from 3 to 4 francs per million gallons, and it is invaluable for the purification of water drawn from rivers or lakes contaminated with sewage or other refuse waters.

It can be applied to any form of filter so long as sufficient time is allowed for the destruction of the living organisms and the oxidation of the organic matter before the treated water reaches the filter bed.

The process has been examined by the French Government Hygienic Committee, by the Belgian Government and the City of Paris, all of them issuing elaborate and eulogistic reports confirming the efficacy of the process.

Mr. Whipple. George C. Whipple, Assoc. M. Am. Soc. C. E., New York City. (By letter.)—The art of water purification has made rapid advances

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during the last decade, as has been well shown by Allen Hazen, M. Am. Soc. C. E., and Mr. J. O. Handy in their admirable papers presented to this Congress. If it is not drawing too fine a distinction, it may be said that during the last few years progress has been made in the art of water purification rather than in its science. The laws of physics, chemistry, and biology, as related to filtration, were developed in great fullness by the experimental researches conducted between 1887 and 1895 by the Massachusetts State Board of Health, and at the water-works of Boston, Louisville, Pittsburg and Cincinnati. Recent researches, while they have added to the general knowledge of these laws, have not in any material sense modified them. Later developments have been in the direction of applying them in such a way as to produce the most efficient and economical structures and mechanisms for accomplishing the desired end. The chemist and biologist have given place to the engineer, who is now the dominating force in this field of action. To adapt to local conditions the principles involved in the purification of water for various purposes and to apply them to the solution of new problems appears to be the work to which the greatest energy will be devoted during the coming decade.

The art of water purification is truly an art. If not one of the "fine arts," it is, at least, one of the "good arts," as some one has termed them, a fact which no one will deny who compares a glass of pure, clear water on a table-cloth of white linen with a glass of the turbid and polluted water too often supplied by our American municipalities; and it is indeed a sign of progress in our civilization that what in years past has been considered as a luxury is now being looked upon as a necessity, not only for hygienic, but for æsthetic and economic reasons.

As has been said, the chemist and biologist have given place to the engineer as a dominating force in the realm of water purification, but the usefulness of the sciences of chemistry and biology has been by no means diminished; rather has it been increased. Modern filtration is founded upon chemical and biological laws, and its efficiency must be continually tested by them. While it is true that in several notable instances in the United States chemists and biologists have become engineers, it is perhaps even more true to say that our engineers have become accustomed to think in chemical and biological terms, and to measure the results of their work by these standards.

The evolution of the methods of water analysis and their interpretation throws an interesting sidelight upon the art of water purification. Even more striking than the rapid development of filtration in this country has been the development of the water-works laboratory. Fifteen years ago such an institution was practically

Mr. Whipple. unknown. To-day there are few cities of any considerable size in the United States where the public water supply is not analyzed with some degree of regularity, either by a chemist employed by the water department, or by the local or State board of health. As an instance of the great change that has taken place in the attitude of city officials toward this service, the following comparison is interesting. In 1852 an analysis of the water supply of the City of Cleveland, which is derived from Lake Erie, was made by Professor W. W. Mather. Eight years later an official report of the Trustees of the Water-Works states that:

"Although the City Council has been frequently urged in the past to procure an analysis of the water * * * yet we cannot see the necessity for a new analysis, as we presume that the water has not essentially changed in character since 1852, when an analysis was made by a person admitted to be eminently qualified for the undertaking."

It was not until five years after this that a second official analysis was made. In contrast, during the past few months an investigation of the same water supply has been completed, in the course of which more than a thousand samples have been analyzed; and, for the future, arrangements have been made to have daily samples collected for analysis.

Another illustration of the growing appreciation of analytical work is the Mount Prospect Laboratory of the New York Water Department which was established in 1897 by the City of Brooklyn. Before that time, the local Health Department had maintained a nominal supervision of the Long Island watersheds, which supply the city. During 1897, severe growths of algæ in the distribution reservoirs turned the attention of the community to the quality of the water and resulted in the establishment of a permanent laboratory at Mt. Prospect by the Department of Water Supply. The work grew rapidly, and when Brooklyn became a part of Greater New York it was extended to cover all the water supplies of the greater city. The rapidity of its development is well shown by the number of samples of water analyzed each year from 1898 to 1903.

1898	2 180
1899	2 393
1900	2 707
1901	3 029
1902	6 021
1903	16 000 (approximately).

The increase during the last year was due to a special investigation of the water resources of Eastern New York made for the Commission on Additional Water Supply.

Although the Mt. Prospect Laboratory is the largest one of its kind in America, there are a number of others where hundreds of

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samples of water are analyzed annually in connection with the supervision of public supplies, not to mention the experiment stations. It would be a very conservative estimate to say that not less than 50 000 samples of water are analyzed each year in the United States by public authorities.

Not only has there been a great change of attitude in regard to the appreciation of analytical work during the past two decades, but the character of water analyses has been greatly altered, and the ideas with respect to interpretation of analysis have undergone radical changes. In Professor Mather's analysis of Lake Erie water, above referred to, he included simply the determination of specific gravity, the number of grains per gallon of "solid matter," "loss on ignition," "earthy and saline matter" and "organic matter," with a statement of its color and transparency. A number of years later, the methods of water analysis which had been developed abroad by Wanklyn, Chapman, Smith, Tidy, Frankland and others were introduced into this country by Mallet, Smart, Leeds, Nichols and others. These methods form the foundation of the modern chemical analysis of water. The bacteriological examination of water did not develop until later. It was during the classic investigations conducted by the Massachusetts State Board of Health, in connection with the examination of the water supplies of the State, and the experiments at Lawrence on the filtration of water and sewage, that the various analyses were co-ordinated and given the form in which they are to-day so well known, and in this the chemical work of the late Dr. T. M. Drown and the biological work of Professor William T. Sedgwick and their able assistants cannot be too highly estimated. This work had its brain center at the Massachusetts Institute of Technology.

The work done by the Massachusetts State Board of Health during the years from 1887 to 1890 was the beginning of a new era in the development of water analysis. This was due in part to use of the new methods of biological study then coming to the fore, but chiefly to the recognition of the interdependence of the various parts of the analysis and to their limitations. This resulted in the establishment of more rational methods of interpretation. Since the dates mentioned the principal determinations have not been greatly altered, although they have been modified to some extent to adapt them to different conditions. Thus, determinations which were of little importance in the case of the clear waters of Massachusetts were found to be of great importance in the case of the more turbid waters of the Western and Southern States. Methods for determining the amount of suspended matter in the water thus became necessary. Modifications in the method of determining hardness were required for similar reasons. The experiments upon mechanical

Mr. Whipple. filtration which involved the use of coagulants necessitated the determination of other constituents of the water, such as the alkalinity, the amount of dissolved oxygen and carbonic acid, the amount of iron, etc. Thus, for a number of years after the publication of the special reports by the State Board of Health, the chemical analysis of water grew more and more complicated. The methods of bacteriological examination also increased in complexity. New kinds of culture media were devised, and important variations made in technique. Numerous special tests for determining the presence of particular species of bacteria were tried, and all but a few of them cast aside. The microscopical examination also began to assume an increasing importance, and the physical examination was added to the others.

A complete analysis of water is becoming, therefore, a rather formidable affair, and, coupled with the rapidly increasing need of the analysis of large numbers of samples, this is affecting the practice of water analysis in several ways. It is causing the elimination of redundant determinations, is leading to the introduction of rapid methods in laboratory work, particularly for use in the field, and is showing the need of the adoption of standard methods of analysis, and a uniform manner of expressing results. In short, it is leading to simplification and standardization. The movement is really a sort of crystallization of the new ideas which have been brought forward during the last decade. In this respect its status is the same as analytical work in other departments of applied science.

To illustrate some of the changes which have taken place a few examples will suffice.

The amount of organic matter in water is shown more or less exactly by the loss on ignition, the oxygen consumed, the nitrogen as albuminoid ammonia, the total nitrogen by the Kjeldahl method, the color and the microscopical examination. Of these the last two taken together best show its character, while the others indicate only its quantity. Often it is a waste of time to make all these determinations, as some of the data serve merely to corroborate the others. The loss on ignition, the oxygen consumed and the total nitrogen in the case of drinking water may be frequently omitted without the loss of any vital facts. Omissions of this character must be made advisedly, however, and only with a knowledge of the local conditions relating to the sample under analysis. In the case of sewage, for example, the determination of total nitrogen may be of greater value than the determination of the albuminoid ammonia, while the estimate of color may give no idea of the amount of organic matter present. In the case of most drinking waters, however, the combinations of color, microscopic organisms and the amount of nitrogen as albuminoid ammonia serve to give a true

picture of the amount and character of the organic matter present. **Mr. Whipple.**

As to the simplification of methods, progress has been made chiefly in two directions: the use of permanent standards for colorimetric determinations; and the introduction of optical methods for measuring the amount of suspended matter. Permanent colorimetric standards for the determination of nitrogen as ammonia, nitrites and nitrates and for color and iron, save much time in the analysis, especially in large laboratories, as they do away with the necessity of making up long series of standards for comparison with the samples being analyzed. They are also of much value for field work.

The method of estimating the amount of suspended matter in water by measuring its turbidity is now in very general use. Several optical methods are used for this purpose, descriptions of which may be found in the files of the *Technology Quarterly*. The generally accepted standards of turbidity and color are described in Circular No. 8 of the Division of Hydrography of the U. S. Geological Survey. In addition to the determination of suspended matter in water, somewhat similar optical methods are coming into use for measuring the amount of precipitates in the chemical analysis by turbidimetric readings instead of weighing them. These are somewhat less accurate than the old gravimetric methods, but they may be often used with advantage where only approximate results are needed, and where there is need of rapid results.

It has been known for a long time that some of the chemical methods involved in the analysis of water are wanting in precision, and that different chemists sometimes obtain very discordant figures. This is something which is too common to all technical analyses, but, perhaps, it is particularly true in the case of drinking water, where the substances to be tested for are so very minute. It is even more true in the case of the bacteriological examination of water, as the science of bacteriology has scarcely emerged as yet from its infancy. As a rule comparative analyses of the same water made by specialists in the large laboratories give concordant results, but analyses made by the general chemists, who only occasionally do this kind of work, are likely to vary greatly. There are few analytical operations where minute differences of technique exert greater effects on the results than in the case of a water analysis.

The question of standardization of methods is now receiving much attention from analysts. In the United States, this subject is being carefully considered by a committee of the Laboratory Section of the American Public Health Association.* Three preliminary reports have already been issued, and the final report is

* Of this committee, George W. Fuller, M. Am. Soc. C. E., is Chairman, and the writer is Secretary.

Mr. Whipple. expected early in 1905. Engineers will be interested in this report, not so much in regard to the detailed methods of analysis as in the manner of stating the results. The old mode of expression was by the use of "grains per gallon." This was gradually superseded by "parts per 100 000," and, at the present time, the most common method is to use "parts per million" or "milligrams per liter," which is practically the same thing. The latter has the considerable advantage of enabling one to make greater use of whole numbers and small decimals, so that the results are more readily handled. Engineers doubtless appreciate also the present tendency of analysts to drop all significant figures and decimals which are beyond the limits of accuracy, or which are of no practical significance.

There has been also a gradual change during recent years in the emphasis placed upon different parts of the analysis. While, in the work of the Massachusetts State Board of Health above referred to, both bacteriological and chemical examinations were made at the Experiment Station at Lawrence, the chemical analysis was chiefly relied upon in the examination of the public water supplied to the State. Improved methods of bacteriological examinations, however, have shifted this emphasis somewhat, and, at the present time, greater weight is perhaps given to the biological and physical examinations, than to the chemical analysis so far as sanitary questions are concerned, although all are necessary to a complete understanding of the quality of the water. Thus, the efficiencies of filters are judged by their powers of removing bacteria and turbidity rather than by their effect upon the chemical analysis of the water. The test for *Bacterium coli* is assuming an importance greater than that of the determinations of free ammonia, nitrites, etc. These, however, are chiefly movements toward differentiation, the different parts of the analysis being made use of according to the nature of the problem involved. It is, perhaps, fair to say that recent investigations of the organic matter in water are making greatest progress along biological lines, and that the advances being made in the chemical analysis are related chiefly to the mineral constituents.

No other feature of water purification, perhaps, has been more marked during the last decade than that of mechanical filtration. From being a proprietary device, loudly heralded by its promoters, but viewed askance by the engineering profession, it has become a means of water purification recognized by the highest authorities as having merits for the treatment of certain kinds of water. Capable of great elasticity in design, it may be at times used with economy in place of slow sand filters and give results equally satisfactory if properly operated. As a general rule, however, sand filters are more satisfactory in the long run, where they can be used. Mechanical filters involve the use of coagulants. In the vast majority of

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cases sulphate of alumina is used for this purpose, but a number of other chemicals have been suggested, and some of them are in practical use. The popular prejudice against the use of chemicals seems to be gradually passing away, yet in certain places it is still strong. Thus in St. Louis the popular prejudice against the use of alum in clarifying the water is said to be so intense that a local engineer has said "it is very doubtful if alum could be used, no matter how excellent the results which might be obtained." One reason for this prejudice was well illustrated by the following expression used in an editorial in one of their local papers: "We don't want to drink puckered water." In Philadelphia a similar prejudice was a potent factor in causing the adoption of the particular form of purification works now being installed there. Like most unreasonable prejudices, the fear of alum is based on ignorance of the facts, and with better knowledge it is passing away except among the ultra-conservatives. This change in public sentiment has been one of the features of the last decade.

Chemicals are now being used not only with mechanical filters, but with sand filters, with sedimentation basins, and even in ordinary storage reservoirs. This phase of water purification seems destined to assume an increasing importance during the next decade. It is impossible to soften a hard water, to decolorize a water deeply stained with organic matter, or to clarify perfectly a water made very turbid with clay without the use of chemicals, and it has been recently found that, by chemical means alone, unaccompanied by filtration or sedimentation, some of the most troublesome algæ may be removed from reservoirs. It has been suggested even that typhoid infection may be removed from water by the use of chemicals alone.

Of the methods of chemical treatment which have received notice during the past few years, the most important are the use of lime and iron (taken together) as a coagulant, and the use of copper sulphate as an algæcide. The use of ozone, the hypochlorites, ferrochlore, etc., which have attracted considerable attention abroad have received but little practical attention in this country and cannot be considered as having yet emerged from the experimental state. Whether or not they ever will remains to be seen. Ozone can never be used practically until it can be manufactured more cheaply than at present; and there are certain objections to the use of chlorinated compounds, which will prevent them from ever taking an important part in the art of water purification. The use of sulphate of iron and lime to form a coagulant in connection with sedimentation and mechanical filtration has been carried on for such a length of time that its usefulness and the limitations of its use appear to be now understood with a reasonable degree of certainty. In the case of

Mr. Whipple. waters which carry large amounts of suspended matter, but which have a low color, the use of lime and iron may be sometimes more economical than the use of alum. Where, however, the amount of organic matter in the water is comparatively large and the water highly colored, the use of alum appears, at the present time, to be more satisfactory. Unless managed with the greatest care the iron is likely to form compounds with the organic matter, which are difficult to remove. The use of this double coagulant requires the exercise of greater care on the part of the operatives, a fact which has an important bearing upon the practical operation of a filtration plant. The relative applicability of different coagulants must be considered for each particular case. In those plants where lime and iron are used, lime is sometimes added in the form of a clear solution of lime-water, but most often as milk of lime. The former gives very much better results, but the large size of chemical tanks required and the time needed for dissolving the lime are necessary difficulties attendant upon the use of the clear solution.

In some cases where lime and iron are used, the coagulated water has a strongly alkaline reaction, and deposits of lime have been known to form on the pipes, valves, etc., through which the water flows. In time such deposits are likely to have an injurious effect on meters, valves, etc. They have been known to increase the size of the sand used in mechanical filters to a considerable extent. In one case, the writer obtained a sample of sand from a filter where lime and iron were used, which was found to have an effective size of 0.62 mm. After the accretions of lime had been removed from the sand by the application of hydrochloric acid, the effective size of the sand was reduced to 0.42 mm. Thus far this increase had not seriously affected the results of filtration, but should the action continue it would be only a question of time when the results would be impaired. In spite of these objections which it is possible to overcome by recarbonating, it seems probable that sulphate of iron may be used as a coagulant in some cases with good results and at a lower cost than alum, but as a coagulant for general use, the present indications are that alum will continue to be the most economical and efficient.

The use of copper sulphate as a method of destroying or preventing the growth of algæ in water supplies* was first brought to general public notice by Dr. George T. Moore and Dr. Karl F. Kellerman in May, 1904. The use of this material as a fungicide has been practiced in Europe for a long time, and it has been a matter of general knowledge to botanists and bacteriologists that copper salts had a high degree of toxidity for the lower forms of life, and especially for unicellular organisms. To Dr. Moore, however, be-

* Bulletin No. 64, Bureau of Plant Industry, U. S. Department of Agriculture.

longs the credit of demonstrating its practical applicability to the clarification of large bodies of water. Although it is only six months since this matter was made public, the method has been so successfully applied in many instances that there can be little doubt that it is destined to play henceforth an important part in the treatment of waters which give trouble from growths of microscopic organisms. Mr. Whipple.

The method of application consists simply of dissolving copper sulphate in the water by putting crystals in canvas bags and drawing them back and forth across the pond or reservoir to be treated until solution takes place. Although this operation is a simple one, it is necessary that judgment be exercised in the amount of chemical necessary as well as in the method of distribution. It is desirable to use as small an amount as possible in order to save expense and on account of the poisonous nature of the chemical used. In treating large bodies of water, account must be taken of the character of the organism present, the chemical quality of the water, the temperature, etc., and allowance must be made for any thermal stratification which may exist in order that a proper distribution of the chemical be obtained. The applications made thus far indicate that some algæ are much more easily killed than others. The blue-green algæ, or the *Cyanophyceae,* appear to be particularly susceptible to its influence. Judging from the nature of the organisms, *Uroglena, Synura* and similar flagellated protozoa ought also to be easily killed. Diatoms and other organisms which have cell walls which are more dense, or which are less easily penetrated by the solution, are killed with greater difficulty and, therefore, require larger amounts of copper. Fortunately, however, those organisms which are most troublesome by reason of the bad odors which they produce appear to be the ones most easily killed. In many cases the application of copper sulphate, in the proportion of one part of the crystallized salt to 8 000 000 parts of water, is sufficient to clear the water of the blue-green algæ. The quantities necessary to be used in the case of other organisms are greater than this, and some of them will probably require nearly as much as 1 part in 2 million, or even 1 part in 1 million. The frequency with which the chemical must be applied yet remains to be determined. If, as now appears, the spores, as well as the vegetative cells, of the blue-green algæ are killed, one application should last for a considerable length of time; but at present it is perhaps too early to make any definite statement in regard to this. In fact, a number of practical points in connection with the use of copper remain to be determined. For example, it is possible that by adding just enough copper sulphate to destroy the blue-green algæ the field may be cleared for the growth of other organisms which may not have been killed by the application of the

Mr. Whipple. weak solution. Thus other and larger doses may be afterward necessary. There is a further question also, as to whether some of the microscopic organisms may not in time become so used to the chemical that its toxic properties upon them may be lost.

After copper sulphate has been applied to the water much of the copper is afterward precipitated as a basic carbonate. This salt is, however, slightly soluble in water and is quite soluble in water which contains free carbonic acid in solution. It is to be expected, therefore, in actual practice that much of the copper which has been added to the water will remain in solution, but just how much will depend largely upon local conditions. The chief objection which naturally arises in connection with the use of copper is its poisonous character. There is little reason, however, to believe that anything is to be feared from its use in very dilute solutions. Copper is an element which is taken into the body more frequently than is generally realized, as it is used in the preservation of many kinds of canned goods, in medicines, and, in the past, to a considerable extent, by dentists in filling the teeth. Even in water it is not always absent. It may be detected readily in water which has passed through brass pipes, and the writer has observed it in rather large quantities in hot water which has passed through the copper boilers which are so largely used in connection with systems of hot-water heating. Should the use of copper sulphate prove as successful in preventing the growth of algæ as now appears probable, it will have a considerable effect in reducing the need of covering reservoirs and may otherwise affect engineering practice.

It is also claimed that copper sulphate may be used as a disinfectant for water supplied on a large scale. Laboratory experiments indicate that its toxic effect on typhoid fever bacilli, *Bacterium coli,* and other ciliated bacteria is quite marked. No results, however, have been yet obtained such as to warrant confidence being placed in this method of protecting the water supply against infection. It is possible, however, that it may have a limited use in the treatment of local sources of pollution, sewage, effluents, etc., where large quantities of the chemical may be used with subsequent dilutions to a point which would be unquestionable. At the present time this whole subject is one upon which it is impossible to speak with any degree of assurance.

One important subject of water purification, namely, water softening, is referred to very briefly by Mr. Hazen, although it is discussed at length by J. O. Handy in another paper presented to this Congress on "The Purification of Water for the Production of Steam." It is not the steam user alone, however, who is interested in water softening. Every one knows that a soft water is more desirable for the general purposes of a public water supply than hard

water. A hard water wastes soap in the laundry, compels the use of washing soda, or other chemicals which injure fabrics, making the washing of clothes a longer, more troublesome and more expensive process. It forms an unsightly "curdle" with soap when used for the toilet and affects the skin unpleasantly. It forms a coating on the inside of the tea-kettle, and sometimes deposits a sediment at the bottom. It is unsatisfactory for cooking. Vegetables, especially potatoes, are not as thoroughly softened by boiling. Tea is less perfectly steeped, the resulting color being darker, but the aroma not as strong. Hard water is objectionable for boilers, as it produces scales, wastes coal and shortens the life of the boiler. It is objectionable in many of the industries, especially when used in connection with chemical processes, as for example, in paper mills. Mr. Whipple.

Some physiologists claim that hard water is less desirable for drinking purposes than soft water, and agents for various forms of distilling apparatus have magnified these supposed objections to an absurdity. There do seem to be plausible reasons for believing that water highly charged with mineral salts is less satisfactory than soft water for some people, and the change from a soft to a hard water often occasions temporary intestinal derangements, but there is no statistical evidence to show that the differences in hardness found in ordinary public supplies have any great practical significance on the public health. The point at which a water becomes objectionably hard has never been exactly defined. Standards of hardness vary in different parts of the country. The boiler fireman considers a water soft, if he does not find it necessary to blow his boilers frequently, or to use a boiler compound; the laundress considers a water soft, if she does not have to use washing soda to obtain satisfactory results; the ordinary person, washing his hands, considers it soft if common toilet soap will quickly produce a "suds" without "curdling." As a rule, these conditions obtain when the total hardness of the water does not exceed 25 or 50 parts per million. The limit cannot be placed exactly, because the character of the hardness, *i. e.,* whether it be due to sulphates, or merely to carbonates, must be taken into consideration. Speaking broadly, however, a water which has a hardness above 50 is well entitled to the appellation "hard," and above 100 the water may be called "very hard." The difference between 25 and 100 can be detected by the taste.

Frequent attempts have been made by scientific writers to express the money loss to a community from the use of a hard water, but the data for making an exact calculation of that kind are not at hand. It has been assumed by one, for example, that the quantity of water decomposed by soap was equal to 10 gal. *per capita* per day; another has placed this at 11 gal.; another at 3 gal. All these figures would appear to be too high for a city like New York. Two,

Mr. Whipple. or even one gallon, would probably be nearer the truth, for the fact is, that in most domestic uses all the hardness of the water is not decomposed by the soap. This was illustrated by experiment made to determine the amount of soap used in the simple operation of washing the hands.

Twelve persons, laborers, clerks, and professional men, were asked to wash their hands in a basin, using a small cake of Ivory soap and as much water as they ordinarily used for the purpose, the water having a hardness of 24.5. The following day the same persons were asked to wash their hands in a water which had a hardness of 126, using the same cake of soap and the same volume of water as they had used in the first instance. In each case the quantity of water was measured, and the loss of soap was ascertained by carefully weighing the cake before and after being used.

The amount of water used varied from 700 to 1 700 cu. cm., the average being 1 100 cu. cm. The quantity of soap varied from 0.03 to 0.73 g. in the case of the softer water, and averaged 0.34 g.; while in the case of the harder water it varied from 0.17 to 1.60, and averaged 0.67 g. Only 41% of the hardness of the softer water was decomposed by the soap, and only 48% of the hardness of the harder water. In round numbers, it may be said, therefore, that one-half of the hardness was used up. In tub-bathing it was found that a much smaller percentage of the hardness was used up.

From the results obtained in the experiment just related, it has been calculated that a person washing his hands once a day would use 0.27 lb. of soap annually to decompose the hardness of the softer water, or 0.5 lb. in the case of the harder water. This does not, of course, represent the total consumption of soap, as much soap is wasted without doing effective work. The difference between the two figures given, however, represents the effect of the different waters. While ¼ lb. of soap per person annually seems an insignificant amount, it amounts to 130 tons per year per 1 000 000 people, which, at 7 cents per lb., amounts to $18 200 per annum.

Hand-washing represents, of course, but a small part of the water with which soap is used in any household. Dish-washing, laundry uses, bathing, etc., would raise the average quantity to at least 1 gal. *per capita* daily, in which all the hardness was used up by soap. In some communities, the quantity might be larger than this.

The following table shows the amounts of water of different degrees of hardness which will be softened by 1 lb. of standard Castile soap and by some of the soaps commonly used.

In a recent study made by the writer for the Commission on Additional Water Supply for New York City, certain calculations were made to show the difference in value to the city between vari-

ous proposed sources of supply. On the assumption that with ordinary uses 1 gal. of water *per capita* daily would be completely softened by soap and that 1 lb. of the average soap will soften 97 gal. of Croton water (which has an average hardness of about 40 parts per million), it was calculated that this would amount to 1 825 tons per annum per 1 000 000 people, and that at 5 cents per lb. this would cost $182 500. It was further calculated that to double the hardness of the present water would increase the consumption of soap in the Borough of Manhattan by about $275 000 annually. This estimate took into account only the cost of soap used for domestic purposes and did not include the other losses incidental to the use of a hard water. These, if they could be expressed in dollars and cents, would probably more than equal the cost of soap. Mr. Whipple.

TABLE SHOWING THE RELATION BETWEEN THE HARDNESS OF WATER AND THE AMOUNT OF SOAP REQUIRED TO HARDEN IT.

Hardness, parts per million.	Number of cu. cm. of standard soap solution for 50 cu. cm. of water.	Number of grams of standard soap per gallon of water.	Number of Gallons of Water Softened by One Pound of									
			Standard Castile Soap.	Ivory Soap.	Babbitt's Laundry Soap.	Sapolio.	Bon Ami.	Gold Dust.	Pearline.	Pear's Hand Soap.	Colgate's Cerosa Toilet Soap.	Average (omitting the standard Castile Soap).
20...	2.1	1.11	409	196	138	102	143	165	167	187	235	167
25...	2.4	1.27	358	174	121	90	125	145	147	164	206	147
40...	3.6	1.91	238	115	80	59	83	96	98	109	137	97
50...	4.3	2.28	200	96	67	50	70	81	82	92	115	82
75...	6.1	3.24	149	67	47	35	49	57	58	64	80	57
80...	6.4	3.49	130	70	44	33	45	52	53	60	75	54
100...	7.8	4.13	110	53	37	27	38	44	45	50	63	45
125...	9.5	5.04	90	43	30	25	31	36	37	41	52	37
150...	11.1	5.89	77	37	26	19	27	31	32	35	44	31
175...	12.7	6.74	67	32	23	17	23	27	28	31	38	27
200...	14.3	7.59	60	29	20	15	21	24	25	27	34	24

The people of this country are just beginning to realize the importance of having a soft water rather than a hard water. It is true that there are no large municipal water-softening plants in the United States at the present time. There is, however, a small water supply at Oberlin, Ohio (consumption about 200 000 gal. daily), where the public water supply is being softened by the application of lime and soda, followed by sedimentation in an open basin and filtration through a mechanical filter of the pressure type. A municipal plant is in operation in Winnipeg, Canada. Other plants in the United States are under consideration.

Mr. Whipple. Although many advances have been made recently in the art of water softening, as shown by the paper of Mr. J. O. Handy, presented before this Congress, the subject is one which at present is clouded with some uncertainty. It is the one phase of water purification where the science is lagging behind the art, and it seems probable that no very rapid developments may be expected until after the subject has been submitted to a more thorough scientific study than has thus far been given to it. It is quite possible that the new theories of physical chemistry, when applied to this subject, may throw such light on the condition of the various compounds of lime and magnesia present in dilute solution, as will tend to clarify present views and establish a more rational method of treatment. Much is to be expected along these lines during the next decade.

Mr. Jordan. EDWIN O. JORDAN, ESQ., Chicago, Ill. (By letter.)—The writer has been particularly interested in that portion of Mr. Hazen's paper dealing with the reduction of the typhoid fever death rate, due to change in water supply. Mr. Hazen's computation which indicates that, in addition to the reduction in deaths from typhoid fever, there occurs a similar reduction in deaths from other causes, and that this also is attributable to a change in the water supply, is certainly very striking. There is one suggestion which the writer would like to offer concerning a possible explanation of this circumstance.

It is well known that the obscure character and variable symptoms of certain cases of typhoid fever lead not uncommonly to a mistaken diagnosis. There is no doubt that in every considerable body of vital statistics some cases of genuine typhoid fever are reported under other names. It need hardly be said that this is particularly true as regards the deaths reported under the captions "typho-malarial fever," "malarial fever" and similar designations. In the Northern United States, the majority of the deaths reported under these headings are deaths from typhoid fever. The effect of filtration well illustrates this point. In the City of Albany, N. Y., there were 37 deaths reported under the heading "malarial diseases" in the four years, 1891-94, and 23 deaths in the four years, 1895-98, while for the four years following filtration (1900-03), there were but two deaths under the same head.

It must be remembered also that a marked improvement in methods of diagnosis of typhoid fever has taken place during the last decade. One result of this has been that deaths formerly reported as occurring from other causes are now correctly reported as due to typhoid fever. This transfer to the column of typhoid deaths naturally diminishes the deaths reported from general causes and must, at least, partly explain the relation pointed out by Mr. Hazen. It may also serve to explain why the apparent reduction in deaths

from typhoid fever is sometimes less than would be reasonably anticipated. The suggestive facts brought out in the paper indicate that other items under the reported deaths in official health reports might repay examination. Mr. Jordan.

EDMUND B. WESTON, M. AM. SOC. C. E., M. INST. C. E., Providence, R. I. (By letter.)—Under his heading, "Experiments," Mr. Hazen has not mentioned the water-purification experiments that were conducted under the direction of the writer for the City of Providence, R. I., during a period of about ten months in 1893-94. Mr. Weston.

The writer's report of the Providence experiments, comprising 182 pages, was published as an appendix to the Annual Report of the State Board of Health of Rhode Island for 1894.

As some of the problems encountered during the experiments were entirely new, the writer was allowed the privilege of retaining for consultation, whenever he deemed it advisable, a number of the highest chemical and bacteriological authorities in the United States, whose advice was of great assistance.

Slow sand filters and mechanical filters were used in making the experiments. The slow sand filters were not operated as such, however, after about the first three months, as it was thought that sufficient information was then available to demonstrate all that was necessary under the circumstances, including the published data relative to the very valuable experiments that had been made with slow sand filters at the Lawrence Experiment Station of the Massachusetts State Board of Health.

The experiments at Providence with the mechanical filters were the first of any magnitude that were ever made with these filters in order to ascertain their efficiency for the removal of bacteria, and they attracted considerable attention at the time, and the portion of the writer's report devoted to mechanical filtration was discussed in several of the leading technical journals of the country.

The late W. Kuemmel, the eminent engineer of the Altoona Water-Works of Germany, who was considered one of the best authorities upon slow sand filtration in Europe, was traveling in this country in 1893, and in July of that year he spent a day with the writer at the Providence experimental filter plant examining the results of the experiments. Mr. Kuemmel expressed himself quite favorably in regard to the experimental plant, the manner in which the experiments were being conducted, and the results that had already been obtained. As he was taking leave of the writer, he pleasantly remarked to the effect: that while he would gladly welcome any new knowledge in connection with the purification of water, he could not help but wish that the experiments with the mechanical filters would not be an unqualified success, for if they were, he feared that the process of purification of water by slow sand filtra-

Mr. Weston. tion, of which he was a strong advocate, would in a large measure be superseded.

The writer has more than once heard it expressed by those who have made a thorough study of slow sand and mechanical filtration, from both a scientific and practical standpoint, that the results of the Providence mechanical filtration experiments first actually demonstrated that mechanical filtration could be classed as a valuable method of water purification, and not merely a process of straining or clarification, as many had previously contended, and that had not the Providence experiments been made the more elaborate experiments with mechanical filters which have followed, would probably not have been carried out, at least until a much later date than they were, and by far the larger number of mechanical filter plants that have been built since 1894, or which are now in course of construction, for the purification of water of cities and towns in this country and abroad, would not have been contemplated.

Relative Applicability of Different Kinds of Filters.—The experience with the mechanical filter plant at East Providence, R. I., which was designed by the writer, taking into consideration the knowledge gained during the Providence filtration experiments, has shown by five years' service that the water of at least one "eastern stream" can be purified by mechanical filtration.

Developments in the Design of Mechanical Filters.—The writer recognizes the desirability of steel-concrete construction for filter tanks, but such construction is not always admissible. The masonry filters of the four plants mentioned by Mr. Hazen are not the only filters that have been "designed in the light of knowledge derived in the experimental investigation." Since 1895 the writer has prepared plans for a large number of filter plants that have been built, based not only upon the "light of knowledge derived in the experimental investigation," but also upon the practical experience gained from time to time in the construction of these filter plants, and in keeping in touch with the methods of operating them. Among other filter plants having tanks constructed of material other than steel-concrete for which the writer has prepared plans are the following: Nine filter plants that have been built in the United States, ranging in capacity from 1 000 000 to 10 000 000 U. S. gal. per 24 hr., having cypress-wood filter tanks; one filter plant that has been built at Trieste, Austria, of a capacity of 4 000 000 U. S. gal. per 24 hr., having steel filter tanks; one filter plant which is in course of construction at Alexandria, Egypt, of a capacity of 12 000 000 U. S. gal. per 24 hr., having steel filter tanks; one filter plant which is in course of construction at Mansourah, Egypt, of a capacity of 1 000 000 U. S. gal. per 24 hr., having steel filter tanks; and one filter plant that has been built at Mysore, India, of a capacity of

2 600 000 U. S. gal. per 24 hr., having stone-masonry filter tanks. Mr. Weston.
The cypress-wood filter tanks referred to have filter beds 15 ft. in diameter; the steel filter tanks at Trieste and Alexandria have filter beds 17 ft. in diameter; the steel filter tanks at Mansourah have filter beds 15 ft. in diameter, and the stone-masonry filter tanks at Mysore have filter beds 17 ft. in diameter.

Mr. Hazen makes a statement to the effect that in the "newer" filter plants the mechanical agitation of the filter beds during the process of washing is generally secured with air. Since 1898 the writer has prepared plans for 13 filter plants, ranging in capacity from 1 000 000 to 12 000 000 U. S. gal. per 24 hr., 11 of which have been built and 2 are in course of construction, in this country and abroad, and in all the filters of these plants the mechanical agitation is accomplished with rakes driven by power.

Mr. Hazen also states, in effect, that in washing filter beds the results by the use of air for agitating the beds seem to be as good as those with rakes driven by power, and that, in some cases, the agitation of the beds by air or rakes might be dispensed with altogether.

While for convenience and economy of first installation there are times when it is desired to use air for agitating, or to dispense with any agitation other than the upward movement of the water in washing, the writer is firmly of the opinion that the most thorough and efficient method of washing a filter bed is by the aid of rakes. Although the results of relatively short periods of operation of different types of filters may have apparently indicated that equally as good results could be obtained by the aid of air in washing a filter bed, he feels sure that suitable comparisons of the results of long service will show that the advantage is decidedly in favor of rakes.

It would appear as though the observing of the washing of filter beds of filters of the two best types equipped for washing, one in which rakes are used for agitating, and the other in which air is used, should also practically demonstrate the superiority of rakes. For instance, with a 15-ft. filter bed having rakes spaced upon the agitator arms, so that the rakes move in the filter bed in circles about 4 in. apart (parallel with the circumference of the filter) from 8 to 10 times per min., and at the same time the wash water is being forced up through the filter bed at the rate of 8.5 gal. per sq. ft. of filter-bed surface per min. Would not this method seem to indicate that the washing would be much more thorough than by forcing at alternate intervals air and 8.5 gal. of water per sq. ft. of filter-bed surface per min. up through the filter bed?

Mr. Hazen has mentioned an automatic effluent controller designed by the writer. The writer would state in regard to this controller, that he was retained at the time it was designed as consult-

Mr. Weston. ing engineer by a filter company, and immediately after patents were obtained, the writer transferred for $1 his interest in the controller to the filter company just referred to. This was done in accordance with the practice that the writer has always followed, namely, never to hold any financial interest in inventions which come within the scope of his professional work.

Developments in Preliminary Processes.—Mechanical filters of American manufacture were installed in 1901 at York, England, as "roughing filters" for the preliminary filtration of the raw water (without the use of coagulant) before it is filtered through slow sand filters.

Mr. Le Conte. L. J. Le Conte, M. Am. Soc. C. E., Oakland, Cal. (By letter.)—The writer was very much interested in the paper presented by Dr. Kemna, which seems to give us much new light on the subject. It may be safely stated that a large percentage of all the large cities in the United States derive their water supply from surface waters. Very few of these waters are filtered before delivery to consumers. The storage of storm waters has come to be the general practice, and where the minimum annual rainfall is sufficient, economical reasons, more than anything else, override many otherwise objectionable features.

The author refers to Lake Michigan as a fine fresh-water lake, and yet cites Chicago's remarkably poor health record. The unpolluted lake waters are certainly above reproach in every respect. When the facts are known about the Chicago water supply in the past, the wonder is that the lake waters were able to stand such unbridled pollution, such as existed before the Drainage Canal was completed. It simply beggars description. Since the canal has been built, there is a vast improvement in quality, although the troubles are not yet entirely eradicated.

In the case of artificial storage reservoirs, the quality of the impounded waters is not as desirable as might be wished, but after filtration is, from a sanitary point of view, absolutely free from objections. The protection of the water-sheds against pollution is certainly a great problem, which taxes the ingenuity and watchfulness of those in charge very severely. Perhaps the best practical way to protect the lake waters against ordinary foul surface drainage is to plant a belt of dense growth of suitable trees, say 500 ft. wide, skirting the entire shore line of the lake. It is not claimed that this is a perfect protection, but it is in many ways highly conducive toward intercepting and purifying the foul surface waters before entry into the lake, by reason of the dense vegetable surface mould which covers the ground throughout the timber belt.

The storage of storm waters is absolutely necessary in those States where the rainfall is small and erratic. In the case of the

reservoirs supplying San Francisco, there are times when the lakes do not receive a drop of stream water for 600 consecutive days. During such droughts the supply must be kept up exclusively from storage. The quality of the water is then at its worst, and, to be frank, is not as palatable as the best water; but this state of affairs does not last long, fortunately, and then the troubles are all over for another cycle of ten to twelve years or more. Most of the time the storage waters are really very good in quality, and soft and altogether quite desirable. The growth of plants and animals in storage waters has of late years been a fruitful subject for investigation. In the case of the San Francisco reservoirs, where the average rainfall is 40 in. per annum, the troubles are very few and short-lived. Across the bay, at Oakland, where the average rainfall is only 25 in. per annum, the troubles last much longer. From a sanitary point of view, they do not cut much of a figure, but from a palatable point of view, extreme cases become highly undesirable and justly give rise to much public complaint. Stagnation seems to be the main trouble, hence the smaller the average rainfall, the greater the troubles become. Where the troubles are bad and last some time, there is only one safe and reliable remedy, namely, filtration. Mr. LeConte.

The writer thinks that the author's remarks regarding ground-waters are highly commendable. From a hygienic point of view, these waters are far better than surface waters, even when filtered. It is strange to note the prevalent lack of confidence which some of our most intelligent citizens seem to have toward ground-waters in general, that is to say, as to the quantity and reliability of the supply. Nothing could be more fallacious. On any given stream, the region underlaid by ground-waters begins at the head of the delta and extends down stream to the mouth of the river, and even beyond. This region often represents many hundreds of square miles of territory, and the sub-soil is more or less full of ground-waters, with varying qualities, of course, where each tributary comes in. The enormous size of this underground reservoir is alone a guarantee of its permanence, and the only real practical difficulty for the engineer to contend with is the tightness of the water-bearing gravel at each particular site selected. Much judgment is required in making a proper selection for a site for pumping works, and the services of a competent engineer to make such selection should never be overlooked. Now that the country is filling up with new population, the troubles with stream pollution are becoming more pronounced every day, and the relative value of ground-waters as a supply is rapidly on the increase. It certainly avoids the usual dangers of surface pollution and the constant expense of filtration. Among the numerous cities in Europe, which are supplied by ground-waters may be mentioned:

Mr. Le Conte.

In France:	
Angers, population	100 000
Lyons, population	500 000
Toulouse, population	175 000
In Italy:	
Genoa, population	250 000
In Germany:	
Dresden, population	360 000
Halle, population	130 000
Krefeld, population	120 000
Groningen, population	300 000
Cologne, population	350 000
Berlin, with population of	1 800 000
has partly abandoned filtration, and adopted a well supply instead.	
Hamburg, with population of	675 000
is following in her footsteps.	

In our own country we have a large number of ground-water supplies, the most noteworthy being:

Brooklyn, N. Y., population	1 000 000
Memphis, Tenn., population	100 000
Los Angeles, Cal., population	100 000

These well-established facts speak for themselves, and completely refute any attempt to place ground-water supplies under the category of uncertain and unreliable.

The hygienists are largely in favor of ground-waters as a sanitary water supply. Prefiltration seems to be a decided improvement on single filtration, and the final results obtained show practically little or no changes in the number of bacteria per cubic centimeter, no matter how heavily the raw water may be charged with bacteria. This is a highly desirable result, and removes much doubt about permanence of efficiency, so much talked about.

Chemical purification is making rapid strides of late years, and the results obtained are sometimes quite surprising. If properly done under intelligent supervision, good results can be obtained which will command respect. The writer expects that much good will come from these efforts in the near future.

Much interest certainly surrounds the application of ozone to the sterilization of foul waters. The probable cost of the process may be put at one-sixth for installation and one-fourth for operation as compared with filtration. This certainly augurs well from an economic point of view, and furnishes most pleasing hopes for the future. The whole process being dependent upon machinery for

its development must necessarily call for ample storage for sterilized water in order to tide over possible accidents to machinery. Mr. Le Conte.

The writer will watch with much interest the progress made by this most pleasing innovation.

J. P. A. Maignen, Assoc. Am. Soc. C. E., Philadelphia, Pa.—Mr. Hazen's paper is a masterly treatment of the progress of filtration in the United States during the last decade, and it recites in a very comprehensive manner the great amount of substantial work done in this country for the purification of water. Very interesting indeed are the tables given in this paper, particularly those showing the influence of the improved water supply upon the general mortality. One feels on reading Mr. Hazen's contribution that, profiting by the failures, difficulties and labors of the past, we have now entered, in this country at least, on a period of practical work. Much progress may still be expected, but enough is now known to justify municipalities, which are responsible for the public health, in spending the people's money on the improvement of water supplies without fear of failure. Mr. Maignen.

The contributions of Dr. Kemna and M. Bechmann are also interesting, but they leave on the mind a somewhat pessimistic impression. The speaker wishes to make a few observations upon these different papers.

Mr. Hazen uses the expression "modern mechanical filtration" to describe the process of filtering water at a high rate of speed after it has been coagulated. The American reader will clearly understand what is meant, but the European reader will not. Mechanical filtration in Europe is understood to apply directly to systems from which chemicals are excluded and to distinguish them from the processes in which chemicals are used. Thus, plain sand filters used without chemicals would, in Europe, be called "mechanical filters," while systems of filtration with which alum or any other chemical are used would be called "chemical" systems.

The fact that the chief mechanical part of the so-called "American" or "mechanical" filter, namely, the rake—which, by the way, was invented by a French engineer, D'Arcy, half a century ago, under the name of "balai"—is now being replaced by compressed air, and, in some cases, by reversal of water current would tend to render the adjective "mechanical" obsolete. The speaker would therefore suggest that "chemico-rapid" would be more appropriate than "modern chemical."

Some filters, in which charcoal is used, have the capacity of removing from water dissolved metallic salts, such as lead, copper, or iron, and also dissolved organic matter. These are called "physico-chemical" filters, although no chemicals are mixed with the water or introduced into the filtering media. Their action on metallic salts

Mr. Maignen. is called "chemical" because the metal is precipitated as oxide, probably by the action of the air condensed in the pores of the charcoal. The phenomenon is somewhat analogous to that produced by spongy platinum.

The chemical treatment of water, concerning which so much discussion has taken place, is not to be condemned because it is chemical. Only such chemical treatments as are likely to leave in the water some undesirable dissolved matters should be objected to. For instance, water which contains an excess of bi-carbonate of lime (dissolved chalk) and receives an addition of lime water (Clarke's process) is treated chemically, but it is not thereby rendered worse. On the contrary, it is very much improved. The bi-carbonate of lime which is dissolved in the water and makes it hard is precipitated by the addition of the hydrate of lime and removed by sedimentation or filtration. In this case something has been taken out of the water and nothing has been added to it.

Waters containing bi-carbonate of lime and sulphate of lime, when treated with hydrate of lime and sodium carbonate, are also improved. All the lime is precipitated, and nothing remains in the water but traces of sulphate of soda which are not objectionable either for dietetic or industrial purposes.

Waters containing dissolved organic matter may with advantage be treated with potassium permanganate, provided the water be subsequently passed through a physico-chemical filter in which charcoal is used intelligently to remove any excess of permanganate that might be left in the water.

On the other hand, water treated with alum or sulphate of alumina for purposes of coagulation is rendered worse by the chemical treatment. If such water is originally soft, the sulphate of alumina may remain in part undecomposed in the water after treatment. If it is hard and contains bi-carbonate of lime before treatment the sulphate of alumina is decomposed into aluminum hydrate, which is insoluble, and sulphuric acid which combines with the lime to make sulphate of lime, which being soluble renders the water harder than it was before. This is an objectionable result.

Sulphate of copper, which has lately been recommended for the destruction of algæ in lakes and ponds, has also been proposed for the sterilization of drinking water. It is said that one part in 100 000 is sufficient to destroy the typhoid germs, but there is no available data to establish how much sulphate of copper is necessary to destroy all the germs. Sternberg classes copper among the substances which are strongly antiseptic, 1 : 1 111 (salicylic acid, 1 : 1 000; mercuric chloride, 1 : 14 300; silver nitrate, 1 : 12 500). There is, therefore, no doubt as to the power of copper to sterilize water, but considering its antiseptic or poisonous properties, the speaker would

recommend that great care be taken in removing all traces of copper, either by secondary chemical treatment with non-poisonous reagents, or by physico-chemical filtration before water so treated is delivered for consumption. All chemical treatments must necessarily add greatly to the cost of water purification and should be resorted to only when it has been demonstrated that the ordinary filtering processes are not capable of purifying the water in a satisfactory manner. Mr. Maignen.

Those who give their attention to the chemical treatment of water in the future must bear in mind, first, that what is left in the water after chemical treatment is not worse than what has been removed; second, in the case of metallic salts being used as reagents, care must be taken that none of the metal be left in solution in the treated water.

Mr. Hazen points out that:

"It has been clearly and unmistakably proved that for the treatment of very turbid waters the sand filters, successfully used in Europe and on the clearer waters of the Eastern part of the United States, are inadequate." He also states, "In bacterial or hygienic efficiency, the earlier mechanical filters left much to be desired. Some of the newer and better ones are doing as good work as corresponding sand filters."

These observations lead to the conclusion that both slow and rapid sand filters have their limits of usefulness, and that too much has often been expected of them. The next decade will see few, if any, water purifying plants depending solely upon a single filtering operation, even where sedimentation reservoirs exist. Whether the water is habitually or occasionally turbid, it is foolish not to make provision for a preliminary treatment. In some cases, preliminary filters, like those of Lower Roxborough, Philadelphia, will be sufficient to render the water suitable for slow or rapid sand filtration. In other cases, it may be necessary to duplicate the preliminary filtration, or to give the water both chemical treatment and preliminary filtration. This must be determined in each case by reliable chemical, bacterial and financial expert investigation.

The writer fully endorses the statements made by Dr. Kemna, namely,

"All surface waters must be considered dangerous and their use in the raw state for a general supply, in each particular case, either has been, is now, or is likely to be the cause of disease and death."

Of course the nearer we go to the source the less pollution we shall have to deal with, but whether the source of supply is a lake, river, or reservoir, there is always some danger of pollution from decomposing vegetable and animal matter, which can only be guarded

Mr. Maignen. against by filtration. The case of Lake Michigan at Chicago is somewhat peculiar. Before the canal was made, there was little or no natural current in the waters of the Lake near the city. The water drawn for consumption and the sewage returning to the lake may have determined a current of their own between the points of ingress and egress. Now that the sewer canal is in use, the Chicago sewage goes to the canal, but the current induced may bring the Milwaukee sewage toward Chicago. Sewage being warmer than water, there is no general mixing with the surrounding mass. During the first three or four days of its existence, the sewage undergoes fermentation, which keeps all the decomposed particles in suspension, and, at this stage, there is practically no real sedimentation.

Reservoirs are useful as storage basins to permit repairs to pumping machinery or rising mains, and also to draw from in times of freshets, thus allowing the worst water to pass by; but they are of very little use for the purification of water unless they are very large.

Dr. Kemna cites the epidemics at the Gelsenkirchen Barracks, and at Metz, and he adds, "the Emperor interfered personally in his usual energetic way." It would be very interesting if Dr. Kemna could tell us what the Emperor has done in the matter. Was the old supply of water cut off and a new one provided, or has a system of water purification been installed, and if so, what is the system and what results have been obtained? It would also be desirable to know why the waters of the Lakes Tegel and Muggel, which supplied Berlin, were abandoned. The case of Rotterdam where the slow sand filters are accused of "having been the actual cause of typhoid fever" is not very encouraging for the friends of slow sand filtration. Dr. Kemna explains that the sand was "rather coarse," and that the filters were "worked at a somewhat high speed." More information upon this subject would be very interesting. The only encouraging feature of Dr. Kemna's treatment is his trust in the prefiltration or scrubbing of water.

The account given of the efforts made to treat water by ozone and chlorine does not show any very practical result. On the whole it must be granted that the student in the art of filtration will have great difficulty, after reading Dr. Kemna's paper, in making up his mind as to what is the best method or combination of methods for the purification of municipal water supplies.

The same note of disappointment runs through M. Bechmann's paper. What he says of filtering galleries is perfectly true; a great deal of water drawn from the galleries is ground-water, and when there is filtration from the river, the "silting up of the filtering surfaces diminishes the supply and necessitates successive and frequent extensions of the galleries." It would be very interesting if

M. Bechmann could furnish complete data from the 57 cities in France which use this system of water supply, inclusive of the date of the establishment of the galleries, the quantity of water obtained daily at the beginning and since that time, the various extensions in each case, and a statement concerning the proportions of ground-water and unfiltered river water. Such data would be very welcome to those who may contemplate some such system of so-called "natural filtration." Mr. Maignen.

M. Bechmann, alluding to the Nancy galleries, states that:

"Dr. Imbeaux * * * has built an open canal through the gravel and conducts through it the river water parallel with the gallery, and on the opposite side of it from the bank of the river."

This has the effect, says M. Bechmann, "of making both sides of the filter gallery equally effective." When the speaker visited these galleries, some ten years ago, there was no filtration on either side of the gallery. Test holes were made all around it, but the gravel was perfectly dry many feet below the level of the water in the gallery. At that time water was flowing directly from the river into the gallery without any filtration whatever. It would be very interesting if information could be obtained as to the actual results of the open canal built by Dr. Imbeaux. It is well known that the contents of cesspools, after having passed through gravel on their way to wells, retain their toxic properties. If the river water is contaminated, what guarantees are there that the gravelly soil through which it has to pass in order to reach the galleries will retain the dangerous impurities? If this simple process of gravel filtration were effective and practicable, why should cities like Paris, London or Philadelphia go to the expense of building high-priced slow sand filters?

The Libourne filters, reported as being built upon the English pattern, were, if the speaker remembers rightly, used in connection with the Anderson metallic iron process. "This system," says M. Bechmann, "is applied to the water supply of 46 cities in the suburbs of Paris." Will the author kindly explain why this system has not been applied also at Saint-Maur and Ivry?

Dr. Kemna in his paper tells us that the "Académie de médicine" of Paris, on July 24th, 1900, "passed a unanimous vote asking for compulsory shutting off of the filtration." In a pamphlet recently issued in Paris, it is stated that in 1903 the

"*Bacillus coli* was found present in the Paris slow sand filtered water 604 times out of 2 535 samples, or 23 per cent."

Will M. Bechmann be good enough to contribute to this discussion the latest available data concerning the operation of the Paris slow sand filters? These data will probably correct the bad im-

Mr. Maignen. pression produced by the preceding statement. We are told that a system of scrubbing or preliminary filtration has lately been established at Ivry, the water being filtered five times through gravel before it passes on to the final slow sand filters, which work at the rate of 2 570 000 gal. per acre per day. The speaker would ask what is the cost per million gallons, inclusive of labor, wash water, power, wasted material, etc., for the preliminary and final filtration, and also the cost of installation of both systems?

Mr. Hazen has alluded to the development of preliminary filtration "in connection with higher rates of filtration" in Philadelphia, under the direction of John W. Hill, M. Am. Soc. C. E., and to the part taken by the speaker in this connection. The system has now been at work nearly a year. The results first found by Messrs. Hering and Fuller, Members, Am. Soc. C. E., on an experimental scale at Philadelphia have been fully confirmed at Lower Roxborough on a large scale with a capacity of 12 000 000 gal. daily. The water obtained at this station at 5 000 000 or 6 000 000 gal. per acre per day, has been as good as that of other stations without preliminary filtration at 2 000 000 or 3 000 000 gal. per acre per day.

Filter plants, in which the preliminary filtration of water will bear an important part, are now being erected from the speaker's plans at South Bethlehem, Penna., Kittanning, Penna., and Lancaster, Penna.

M. Bechmann in his paper makes allusion to some of the inventions of the speaker. He says in substance that the Maignen system of domestic filters through sacks of asbestos cloth filled with "carbo-calcis" * * * has retained a certain vogue, notwithstanding the failures which have attended its application on a large scale.

"This system," says M. Bechmann, "which was tried at Saint-Maur in 1896, did not succeed in meeting the requirements of the contract with the City of Paris, and it was no more successful at Cherbourg, where it was applied to the purification of the water of the Divette."

Concerning Cherbourg, the speaker respectfully submits that the conditions are not exactly as stated. The filter plant was not designed for the purification of water, but only for "dégrossissage" (scrubbing). In the words of the Mayor, M. Liais, to his Councils in session on March 21st, 1896: "The Council asked for the general scrubbing of the water, for which operation the existing system was selected as the least costly."

At the time the amount of money available was very limited. It was not considered necessary to purify all the water used, inclusive of street washing and garden watering, but it was thought sufficient merely to clarify or "scrub" the general supply and have public filtering fountains along the streets and in the squares to filter the

water a second time for drinking purposes, and the plant was designed accordingly. Mr. Maignen.

Several times during the first two years that followed the installation, the speaker urged the desirability of carrying out the original idea, which was, as soon as money was available, to improve the quality of the filtered water by increasing the filtering area and reducing the speed of filtration, which at the time was fixed at the rate of over 70 000 000 gal. per acre per day, and also by providing some system of preliminary treatment, or prefiltration, in order to reduce the quantity of mud going on the filters; but he was advised not to insist and to leave well enough alone, the people and the administration being satisfied.

With regard to the trial at Saint-Maur, in 1896, which M. Bechmann says "did not succeed in meeting the requirements of the contract with the City of Paris," it may not be without interest to the members of the Congress to know what these requirements were, and in what respect they were not met, and also some particulars as to the circumstances which led to the trial. In July, 1894, the City of Paris opened a public competition to all inventors of processes of purification or sterilization of river water.

"The purification," said the advertisement for the competition, "will be considered perfect if the purified water is limpid, without color, if it has no disagreeable taste, if it is sufficiently aerated, if it contains no pathogenic bacteria, and lastly, if the organic matter left in the water is reduced to a minimum, and if there remains in the treated water no noxious substance."

Applications were sent in by 148 inventors with description of processes. Of these, 24 were of the "physical" order (heat); 71 of the "mechanical" class, that is, filtration through sand, charcoal, cellulose, asbestos, porcelain, centrifugal force, etc.; 24 processes were chemical, using lime, lime and magnesia, iron, barytes and iron, lime, soda and perchloride of iron; and 20 processes were of varied character, including oxidation by air and sand, alkaline salts and charcoal, sulphate of alumina and sand, iron and sand, oxide of iron and sand, oxide of iron, sand and charcoal.

Of these different propositions, 106 were thrown out of consideration at the outset as being impracticable; 42 were admitted for further consideration, and 19 were actually tried.

As a conclusion the commissioners considered that the processes in which heat was used were too expensive. The chemical processes were deemed unsatisfactory on account of the great attention required, and the reporting engineer, M. Bienvenue, concluded as follows:

"Mechanical filtration by means of sand or asbestos combined, if need be, with a previous simple chemical treatment, appears still

Mr Maignen. to be the only process capable of meeting the exigencies of the problem."

Mechanical filtration by sand here means plain slow sand filtration, and the allusion to asbestos means the passage of water through sacks of asbestos cloth and charcoal, as proposed at the time by the speaker and experimented upon by the commission. Upon these conclusions, the speaker made the following proposition to the City of Paris, which proposition was accepted:

"I agree to install for the purpose of demonstration an installation of my system capable of furnishing a volume of 1 320 000 gal. per 24 hr. (5 000 cu. m.). This installation shall be made at my expense on ground supplied by the city at Saint-Maur. The conditions which are to be fulfilled by the process are as follows:

"1. The water must be deprived of the greatest part of the germs contained in it before filtration. The reduction in the number of microbes must be at least proportionately equal to that given by the slow sand filter beds adjoining.

"2. It must have a natural and agreeable taste.

"3. It must have no color, and the dissolved organic matter must be reduced by at least 40 per cent. It must contain no added noxious substance.

"4. The cost of the treatment must not exceed 1 centime per cu. m. ($7.20 per million gallons)."

The speaker left Paris to come to this country before the test was completed. While he was in charge all the conditions enumerated above were fulfilled except one, namely, that of the quantity filtered. All the bacteria that were in the applied water were removed. None of the species that were in the river water previous to filtration were found in the filtered water; those found in the filtered water were of a kind not in the river water. They were presumably introduced in the underdrains and piping systems from the atmosphere through 16 ventilating shafts communicating with the collecting system. The water from the slow sand filters adjoining had none of these underdrain bacteria, but it contained nearly always some of the species originally present in the applied water. When seen through a 15-ft. tube, the water which had been filtered through the asbestos and charcoal system was absolutely colorless. The blue sky appeared as blue and the white clouds as white through this depth of water as if there had been no water in the tube. It was not so with the water filtered by the slow sand filter beds. The white clouds when viewed through 15 ft. of this water appeared yellow and the blue sky green, showing the presence of microscopical suspended matter in the water, which was absent from the asbestos-filtered water. The taste of the water was natural and agreeable, and if anything, more so than that from the sand filters. The organic matter was reduced, in proportion, more than 50%, while the reduc-

tion by the sand filters barely reached 20 per cent. The asbestos-filtered water contained absolutely no added noxious matter. Mr. Maignen.

The failure of the plant, if failure it may be considered, was that the quantity of water filtered was not as large as originally expected by about one-half.

The speaker proposed to live up to the requirements as to quantity by providing an extra set of filtering organs, so as to allow those freshly washed a certain period of rest previous to being put into use again. This operation, which is equivalent to intermittent filtration, was found to be the best means of maintaining normal speed. The Engineer-in-Chief at the time, M. Humblot, advised the speaker to let well enough alone. He urged that the main object of the experiment was not quantity but quality; that what was sought was the demonstration of the highest possible degree of purification. There was, therefore, according to him, no necessity for increasing the output; conclusions could be drawn from the work done by the existing plant as well as from one double the size. This is how the matter at Saint-Maur stood seven years ago, when the speaker left France to come over to this country. He would respectfully submit that the Saint-Maur experiment has not been a failure; all that can be said of it is that the experiment has never been finished.

It is well known that when operating on small quantities of matter, it is possible to use refined methods and produce superior results. The Saint-Maur experiment was an attempt to demonstrate, on a large scale, the highest degree of water purification attainable by filtration.

This was done by grouping together 2 112 units or filtering organs of the kind previously used with success on a small scale for domestic and army purposes. The results obtained at Saint-Maur with these filters were superior to those realized by all other processes, and the system can be recommended when a higher degree of purification than that obtained by plain slow sand filters is desired, as, for instance, when there is a bad taste in the water, or dissolved coloring impurities, or when copper sulphate or other metallic reagents are used to sterilize the water. These filtering organs are capable of removing metals in solution.

M. Bechmann gives an account of the "small filters for domestic dwellings" which have had their birth in France. The fact that the subject of so-called domestic filters has been deemed worthy of a place in the communication of the eminent French engineer shows that it is not altogether devoid of interest. These small filters may be of great use in isolated dwellings where nothing but well or cistern water is available, and in towns where there is a general supply, which may break down, as at Rotterdam, Holland, or when

Mr. Maignen. the municipal filters have to be put out of service for one reason or another, as at Butler, Penna. Perhaps filtration engineers may find in these smaller inventions the germ of some principle or principles susceptible of application on a large scale. A few words of discussion in connection with this subject, therefore, may not be out of place.

Time was when all domestic filters were condemned as a delusion and a snare. Then came the period of so-called "germ-proof filters," which were to drive disease out of existence. Now we are told that the efficiency of these filters "is not doubtful when the bougie (unglazed porcelain tube) is frequently cleaned and sterilized." This of course implies that the efficiency is more than doubtful when the tubes are not frequently sterilized. This sterilization, we are also told, is to take place by baking the tube in a dry heat of from 536 to 572° fahr. during half an hour. Apparatus in which such heat can be produced is hardly available in households. Anxious inquirers, therefore, in search of germ-proof filters, will derive little consolation from the information conveyed. Some of the domestic filters mentioned by M. Bechmann, such as those in which a sheet of paper, renewable every day, is used, have not, so far as the writer knows, had any very extensive application. It is some consolation to find, from M. Bechmann's statement, that the speaker's system of domestic filtration "has retained a certain vogue" in its native country, and it may not be without interest to the members of the Congress to consider some of the reasons that may have contributed to the maintenance of this vogue.

The United States Patent Office classifies applications for filter patents under two heads, *viz.*, "porous walls" and "granular beds." If the porous wall filters (unglazed porcelain or natural stone) are made of open or very porous material, or if they are characterized by irregular pores or channels, the filtrate is not satisfactory. If, on the contrary, the porcelain is very fine and close-grained, the quantity of water filtered is exceedingly small. The impurities collecting on the surface quickly block the way, and pressure is required to insure the passage of water. It has been found that bacteria grow in the walls and make their way inside the filter tubes, where they multiply, hence the necessity of frequent sterilization. This may be called a "surface" filter.

Granular bed filters differ essentially from those made of porous walls. They cannot, when quite new, give sterile water like the porcelain filters. The latter come directly from the fire, so that neither the interior of the tube nor the body of the porcelain can contain any bacteria or spores, whereas the materials, sand or charcoal, used in the granular bed filters have been exposed to the air and have collected a vast quantity of air germs, which require nearly

a month to come to life and work their way out with the filtrate. Mr. Maignen. When once a granular bed filter has been freed from what has been called "constitutional" bacteria, the lower or inner layers of sand or charcoal are practically sterilized and remain so as long as they are not disturbed. Thus, for instance, slow sand filters, when quite new, give up a great number of bacteria, but when they have been in use some months they become "ripe." The lower layers of the sand have by this time become practically sterile, and the filtered water is excellent as long as the sand is not disturbed, however great may be the accumulation of mud or bacteria at the surface, which accumulation is well known under the name of "Schmutzdecke." The mud and bacteria may penetrate into the sand ½ in., 1 in., and sometimes 2 or 3 in., but not more when working without pressure. The presumption is that these bacteria, which have but a limited span of life in water, die in the layer of sand, the particles of which are fine enough to imprison them. When the slow sand filters are scraped with care, there is very little disturbance in the quality of the filtrate immediately after resuming operation. In mechanical filters, on the contrary, the whole sand layer is stirred up and the first filtrate after cleaning is always worse than the applied water. It must therefore be held as a good rule for "granular bed" filters that they be disturbed as little as possible.

The filtering organs designed by the speaker and alluded to by M. Bechmann are composed of two layers of charcoal, a thin layer of very fine particles and a thick layer of coarse particles, held between two asbestos cloths. The inner asbestos cloth holds back the fine charcoal. The outer cloth holds back the mud. The cleaning operation, which consists of washing off the mud from the surface of the outer cloth, is made once in two or three months, or once a year, according to the different kinds of water. The granular material itself is not disturbed for two or three years.

The speaker knows of certain granular filters which have not been cleaned for months and years, and at this moment are giving water day after day which may be considered as practically sterile, containing less than 20 bacteria per cu. cm., with applied water containing tens of thousands. No granular filters should be cleaned except when they cease to give water, and the best method of sterilization for granular filters is prolonged usage without disturbance.

The speaker has no data as to the behavior of filtered water stored in open reservoirs; he will have some in a year's time from two different filter plants now being operated under his direction, but he has some interesting data to submit concerning the changes which take place in unfiltered water stored in open reservoirs.

It has been customary of late to say that reservoirs containing one, two, or three days' supply improve the bacterial quality of the

Mr. Maignen. water to the extent of 30 or 40 per cent. This is not strictly correct. The speaker has noticed that while in the warm seasons of the year (May to September) there is a marked improvement in the bacterial condition of the water stored in reservoirs, exactly the reverse takes place in the cold season (December, January, February, March, and April). Thus in Philadelphia, during 1904, the speaker has had samples taken daily (Sundays excepted) from the main pipe bringing the raw river water to the Lower Roxborough settling basin and other samples from the pipe which brings the settled water to the preliminary filters, with the following results:

BACTERIAL READINGS OF RAW AND SETTLED WATER.

1904.	Number of days on which there was a decrease in bacteria.	Percentage of days in which there was a decrease.	Number of Bacteria per Cubic Centimeter.			Temperature.		Number of days on which there was an increase of bacteria.	Percentage of days in which there was an increase.	Number of Bacteria per Cubic Centimeter.			Temperature.	
			Before entering reservoir.	After leaving reservoir.	Percentage of reduction in number of bacteria.	Air.	Water.			Before entering reservoir.	After leaving reservoir.	Percentage of increase in number of bacteria.	Air.	Water.
January...	6	30	75 500	18 780	75.2	23°	36°	14	70	43 500	93 200	114.2	21°	36°
February..	1	4.3	65 000	35 000	46	27°	36°	22	95.7	98 000	189 000	93	21°	36°
March......	7	31.8	57 500	44 500	22	39°	41°	15	68	66 500	113 000	70	41°	40°
Averages..	....	22.1	66 000	32 740	47.7	29.6°	....	....	77.9	69 333	131 733	92.4	27.6°	...
April......	14	82	15 600	7 300	54	52°	51°	3	18	13 400	29 300	119	47°	43°
May.......	16	80	32 200	15 900	51	67°	67°	4	20	11 300	13 600	20	60°	63°
June.......	21	95	23 000	10 900	53	74°	72°	1	5	10 000	14 000	40	64°	75°
July.......	13	72	9 900	3 600	64	79°	77°	5	28	3 100	4 000	29	75°	79°
August....	15	68	20 400	7 200	65	74°	75°	7	32	7 300	10 300	41	79°	76°
September.	21	91	32 800	14 900	55	68°	70°	2	9	3 300	4 100	28	68°	71°
Averages..	....	81.3	22 316	9 966	56.3	69°	....	....	18.7	8 066	12 550	45.5	65.5°	...
October...	18	90	80 500	38 400	52	53°	60°	2	10	40 000	57 500	44	52°	56°
November.	10	48	164 700	106 900	35	40°	44°	11	52	129 045	175 636	36	40°	44°

This table shows two striking features:

First.—During the cold months (January, February and March), the river water is highly charged with bacteria: 66 000 and 69 333 as compared with 22 316 and 8 066 for April, May, June, July, August, and September.

Second.—After passing through the reservoir, the number of bacteria has been reduced to the extent of 47% during 22.1% of the time and increased 92.4% during 77.9% of the time in the cold season, while in the warmer season there has been a reduction of

56.3% during 81.3% of the time and an increase of 45.5% during 18.6% of the time. Mr. Maigneu.

Something analogous can be seen in the report on water purification at New Orleans made to the Sewerage and Water Board by R. S. Weston, Assoc. M. Am. Soc. C. E. This report shows that better percentages of removals of bacteria were obtained after the water had subsided for short periods than after long periods. The following table is taken from that report:

"SHOWING THE NUMBERS OF BACTERIA IN THE INFLUENTS AND EFFLUENTS OF THE VARIOUS SUBSIDING BASINS, THE BACTERIAL EFFICIENCY OF THE SAME, AND THE LENGTHS OF THE PERIODS OF SUBSIDENCE.

" Basin No.	Hours.	Average Bacteria per Cubic Centimeter.		Bacterial efficiency.
		Influent.	Effluent.	
" 1	72	2 000	3 900	— 95 per cent.
" 2	48	2 200	5 500	—150 "
" 3	12	1 900	1 300	+ 32 "
" 3	48	2 000	2 300	— 15 "
" 4	12	1 900	1 300	+ 32 "
" 4	24	2 200	1 900	+ 14 " "

If the daily record published on pp. 82-97 of this same report, from which these general conclusions are drawn, is carefully examined, very interesting data will be found, confirming the speaker's observations as to the seasonal behavior of water in reservoirs.

Basin No. 1 was kept in use from January 8th to August 17th, 1901; the other basins were used for shorter periods; they all showed the same characteristics, reduction of bacteria in warm seasons, increase in cold. It will, therefore, be sufficient to give the record of Basin No. 1. (See table, page 226.)

It is one thing to record the seasonal changes that take place in water stored in reservoirs, and another to explain them.

It has been held that the turbidity and richness in bacteria follow very nearly the same curve. "Turbidity and quantity of bacteria increase together," said the late Colonel A. M. Miller.* This is no doubt true in a general way. The storms which wash the soil and flood the ditches and creeks send into the rivers both bacteria and dead organic matter, so that the organisms and their food are found together. But in the winter of 1903 in Philadelphia the number of bacteria was very considerable in the river and still more

* "Feasibility and Propriety of Filtering the Water Supply of Washington, D. C.," 56th Cong., 1st Sess., Senate Doc. No. 259, p. 32.

Mr. Maignen. so in the reservoirs, notwithstanding the fact that the water was perfectly clear (4 parts per million silica turbidity). To attempt to explain this fact may be vain, yet the speaker would suggest that perhaps the bacteria derived from sewage pollution, being subjected to a colder environment, do not run through the cycle of their existence in as short a time as when the water is warmer; it is notorious that when cultures are exposed to a low temperature, the bacterial growth is retarded, although not prevented altogether. It is known that the higher micro-organisms, such as the *Protozoa* and *Rotifers,* which live on the bacteria, do not thrive in winter, and it may be that in the absence of their natural enemies the bacteria have the field all to themselves and multiply in reservoirs at their ease, while they go through the cycle of their existence in a shorter period and are destroyed by the infusoria in the warmer seasons.

RECORD OF BASIN NO. 1, JANUARY 8TH TO AUGUST 17TH, 1901.

1901.	Number of days on which there was a decrease.	Per cent. of days on which there was a decrease.	Number of Bacteria per Cubic Centimeter.		Per cent. reduction in the number of bacteria.	Temperature.		Number of days on which there was an increase.	Per cent. of days on which there was an increase.	Number of Bacteria per Cubic Centimeter.		Per cent. increase in the number of bacteria.	Temperature.	
			Before entering reservoir.	After leaving reservoir.		Air.	Water.			Before entering reservoir.	After leaving reservoir.		Air.	Water.
Jan. 8th to Feb. 27th.	12	29	2 116	976	53.8	53°	48°	29	71	1 240	12 643	920	53°	48°
Feb. 28th to March 31st.	14	45	2 835	910	67.9	61°	51°	17	55	1 141	4 752	316	61°	51°
April 1st to April 28th.	12	70	3 900	1 533	60.7	65°	57°	5	30	2 860	22 620	690	65°	57°
April 29th to June 27th.	44	93.5	2 496	1 032	58.7	78°	72°	3	6.5	1 100	2 200	100	78°	72°
June 28th to Aug. 17th.	35	94.6	1 465	425	70.9	84°	86°	2	5.4	1 350	2 550	89	84°	86°

It may not be out of place here to suggest a possible explanation of the prevalence of water-borne diseases after heavy rainfalls. We know that specific germs cause specific diseases, that these germs, as spores or desiccated adults, may retain their latent principle of life for days, months or years, in dust, or on dry ground. Just as the grains of wheat or seeds can be kept in barns for years without losing their potentiality, and sprout as soon as confided to moist Mother Earth, so the germs of disease, when washed by the rain

Mr. Maignen.

into watercourses, are incubated in the water after a period which may vary according to temperature and environment, and develop into full-fledged bacteria, producing the temporary epidemics reported every now and then.

We pass ordinances to prevent spitting on pavements and in cars—we little think that the water tendered to us in a crystal glass, drawn from a nickel-plated faucet, after having reflected the silver rays of the sun in a well-kept reservoir, may, a few hours or days before, have received the road wash with its dry sputum, the foul mud of the ditch, with the debris of dead animals, remains of garbage, and, worse than all, the raw sewage from municipal systems. We can, therefore, never be too particular in demanding that the water intended for drinking be subjected to the highest degree of purification attainable.

Allusion has been made to the installation of a mechanical filter at York, England, for the purpose of preparing the water for filtration by the slow sand system, which has been in existence there for three-quarters of a century. We have also been reminded of the double filtration carried on through slow sand filters at Bremen.

The speaker thinks it should be known that at York the rate of filtration of the slow sand filters has not been raised in any way. It is now as before about 1 500 000 gal. per acre per day. At Bremen the plain slow sand filters have been arranged so that when the effluent from any one filter is unsatisfactory as "after cleaning, after refilling with clean sand and when the raw water is worse than usual," the filtrate from the defective filter is sent upon a "ripe" plain sand filter for second filtration (the level of the water in the latter being lowered so as to permit the water to flow thereon). The inventor of the system, Mr. Goetze, says:

> "The water having received a preliminary (first) filtration contains only a few of the elements which produce the 'Schlammdecke' and is, therefore, unsuitable to transform a bed filled with clean sand into a biological filter. Therefore * * * it is necessary * * * that only filters which have been operated with raw water can be used as final filters."

This is not preliminary filtration as understood in the United States. It is double filtration pure and simple, after the manner usual in laboratories, in which, when liquids containing suspended matter are passed through filter papers, the first filtrate does not come out clear, as the pores of the paper are too open, but after passing the liquid over again through the same filter, the pores of the paper become covered by a kind of "Schlammdecke," which insures a clear filtrate.

The system of preliminary filtration designed by the speaker and installed at the Lower Roxborough Filter Station in Philadelphia, which is spoken of in Mr. Hazen's paper, is based upon a different

Mr. Maignen. principle. The speed of filtration in the plain slow sand filters receiving the prefiltered water at this station has been raised to 5 000 000 and 6 000 000 gal. per acre per day.

In the York and Bremen plants, the filtering material used for the first filtration is sand. The filtration takes place downwards, and the mud accumulates on the surface. The average quantity of water that passes through such filters between two cleanings is estimated at 60 million gallons per acre. At Lower Roxborough, the quantity of water that passes through the preliminary filters between cleanings averages 6 000 million gallons or one hundred times more. This can be understood from the fact that the filtration in the latter case takes place upwardly through coke or slag, the smallest particles of which are 1 in. thick, and then through a layer of uncompressed sponge. There is, therefore, sufficient space in the voids of these materials to retain the mud contained in this very considerable quantity of water without clogging.

In the case of the downward sand filters used for first or second filtration, the sand has either to be removed from the bed, as at Bremen, or to be washed by reverse current, as at York. In the first instance, the cost may be estimated at $1.50 per cu. yd. of dirty sand removed and washed. There are about 135 cu. yd. of sand to be handled in this way at each cleaning (1 in. thick over 1 acre of surface). The cost of separating the mud from the sand is, therefore,

$$\$1.50 \times 135 \text{ cu. yd.} = \$202.50,$$

or for a run of 60 million gallons, $3.30 per million gallons prefiltered.

The cost of washing the sand in the mechanical filter is not any less when the labor, machinery and cost of wash water are taken into consideration.

In the Lower Roxborough preliminary filters, the cleaning operation consists of:

1.—Directing a jet of water under pressure on the coarse coke or slag, without taking the material out of the filter bed, the mud being carried down to the drain with the wash water.

2.—Removing the sponge from the bed and washing it in laundry machines.

The total cost of performing these operations does not amount to 75 cents per million gallons prefiltered.

In the downward filtration, there is always a notable loss of head, which may vary from 4 to 14 ft., while in the Lower Roxborough preliminary filters the loss of head does not exceed 1 ft. When the water has to be pumped, the latter is, of course, very much more advantageous than the former.

The idea of two successive filtrations is based upon a rational principle. The speaker became convinced of this years ago in the

filtration of wine through filter cloths. When new wine containing lees had to be filtered, he was met by the following difficulty: If the cloth was fine enough in texture to give the quality desired it did not give the quantity, and if the texture was open enough to give the quantity it did not give the quality. Then he resorted to two distinct operations, one through an open cloth, to remove the coarsest sediment, and another through fine cloth, the ultimate result of which was satisfactory both in quantity and quality. Mr. Maignen.

The object sought in designing the Lower Roxborough preliminary filters has not been to prefilter the water too well. Mr. Goetze and many others hold that the presence of some "elements (suspended matter) are necessary to produce a 'Schlammdecke.'" They are intended to retain the coarse particles, the presence of which in the applied water would bring about the premature clogging of the downward filters.

The removal of turbidity by the Lower Roxborough preliminary filters averages 60% (the suspended matter, 70%). The bacteria are reduced in the proportion of 70 to 80%, and the *B. Coli Communi* about 50 per cent.

The speaker wishes to bear testimony to the practical manner in which the coagulants are prepared and fed to the water. The Water Commissioner, the Engineer and the Chemist in charge are to be congratulated. The chemical treatment of water has of late been much decried in this country, because the coagulant—sulphate of alumina—has been found to have a tendency to impair the potable and industrial qualities of the water, but the reagents here used—lime and iron (the latter in very small proportion)—cannot be criticized from either a hygienic or industrial point of view, provided, of course, no excess be used. The boldness of the plan and the practical results obtained will open a new chapter in the history of water purification. Some fear has been expressed as to the possibility of choking the pipes and faucets in towns, with carbonate of lime. It is a fact that in Europe, where numerous water-softening plants, using lime as a reagent, have long been in use, some trouble has been experienced in the way of choking of pipes when the filtering devices always attached to such plants have proved themselves defective. Precipitated carbonate of lime adheres to the sides of the pipes with much more tenacity than ordinary mud composed of clay and organic matter. No trouble of this kind can occur if care is taken to remove all the suspended matter left in the water after chemical treatment. The speaker thinks that a simple process of filtration could be devised to perform this duty in a satisfactory manner and at a small cost for installation and operation.

J. N. Chester, M. Am. Soc. C. E., Pittsburg, Pa.—While it may not have been Mr. Hazen's intention to convey the impression that mechanical filter construction, prior to ten years ago, lacked the Mr. Chester.

Mr. Chester. ability to purify water supplies successfully, yet it seems to the speaker that unfortunately this statement has crept into the substance of his paper. While in the speaker's opinion the advancement in water purification has been more marked in the operation of the mechanical filter rather than in its construction, the improvements that have been made in the construction of these filters have leaned more to the ease of operation and the reduction in cost of operating than toward their practical efficiency.

In the plants operated by the company with which the speaker is affiliated (The American Water Works and Guarantee Company), there exist to-day several filter plants that were installed more than ten years ago and several others installed as much as fifteen years ago. These filters are still in operation, many of them existing to-day practically as they were installed, and the bacterial and chemical analyses of water show them to be as efficient, so far as bacterial results are concerned, as filters built within the last two or three years.

The first radical change made in the mechanical filter in the United States was the abandonment of the closed or pressure type and the consequent adoption of the open or gravity type. This change tended not so much to increase the possible efficiency as it did to increase the certainty of obtaining good results, by placing the filter bed within reach of the operator at all times, permitting it to be kept more easily in generally better condition, than was the case with the pressure or closed type. This, however, does not argue the impossibility of obtaining good results, due care being exercised, with the pressure or closed type. That the expense at which a satisfactory result can or could be obtained with the closed type of filter is as low as that of the open, or gravity type, no one will attempt to maintain; this, however, does not do away with the fact that there were, and are to-day, conditions which make the closed filter, in a few instances, more applicable than the open or gravity type, and, consequently, there exist to-day, and it is stated authoritatively, several extensive filter plants of the closed type that are doing good work, and that they are doing good work is evidenced by their ability, with the assistance of proper sedimentation, to clarify, even to rendering sparkling, the excessively turbid waters of the Missouri and Arkansas Rivers, which certainly must testify to their ability to do bacterial work, because much of the turbidity which they remove consists of particles smaller than bacteria.

The principal mechanical changes, or changes in design or construction, that have been made are: First, the doing away with the large sand valves formerly used and the extreme distance from center to center, which often reached 18 in., and the grouping of same in centers approximating 6 in., thus securing a better distri-

bution of wash water, thereby reducing the cost of maintaining the bed in good condition and assuring a thorough cleansing at each period of washing. Mr. Chester.

The second change of importance has been in the ability to get rid of the wash water, or the betterment of the design of the wash overflow. Where formerly we expected a particle to be raised from the bed and carried horizontally many feet by a sluggish current to the overflow, to-day, common practice has practically fixed a distance not to exceed $3\frac{1}{2}$ ft. for the lateral movement of any foreign particle arrested by the sand bed, which must necessarily be removed by the reversal or wash.

The third change of importance has been in the design of the sand valve, or the device for separating the water from the sand and distributing the wash water. Where formerly the sand was permitted to come in contact with the valves or screens, thus cramping the area of exit of the water from the sand (which, arguing from the standpoint even of a graduated sand bed, should have been at least 50% of the filtration area at the surface), the introduction of a layer of sand supporting the gravel over the sand valves gives practically as great an area of exit as there is filter area.

Then again, in addition to the protection of the sand valves secured from the gravel, their construction has been changed in many respects, and most modern designs guard against the sliming or coating which formerly followed the necessary use of lime to assist in the decomposition of sulphate of alumina at times when the carbonates of the water were low, until to-day the cost of cleaning and renewing such valves has been brought down to a minimum.

The fourth and probably the greatest advancement has been in the ability of the laymen in charge of a filter plant to grasp and comprehend the methods determining the alkalinity or temporary hardness of the raw water supply, thereby providing for the introduction of the coagulant in proper proportion and in this way protecting the filtrate, and in general to handle practically a mechanical filter with a degree of intelligence approaching the maximum, which was formerly thought attainable only by the graduate chemist.

To-day a filter consists of what it has for centuries, *viz.*, a sand bed of a certain fineness (depending somewhat on the work to be done, and the coagulant used, but at any rate producing the result, whether through the aid of a chemical reagent, or, as in the slow sand process, with a consequent film around the sand grains, to arrest the suspended matter consisting of turbidity and micro-organisms) coupled with a device or arrangement at the bottom of this sand bed that will effectually separate the filtrate from the sand and also distribute the reverse current and effect a cleansing of the bed with the assistance of the wash overflows, or the scraping

Mr. Chester. of the sand as in the slow sand filter practice; and whatever else may have been added has only been to cheapen the cost or to increase the ease of operation.

In the paper under discussion, the author has apparently forgotten, or neglected, the small Southern or Western city which is compelled to derive its water supply from a turbid stream, and which is frequently located so as to render slow sand filtration impracticable or impossible. It may consume only from 500 000 to 3 000 000 gal., and be surrounded generally by conditions for which the intelligent engineer must necessarily prescribe mechanical or rapid filtration, be he an advocate of one or the other. Such conditions have frequently confronted the speaker.

The reliability of the mechanical filters must necessarily increase with the size of the necessary adjunct, the settling or coagulating basin, which, acting as it does as a mixer, and, consequently, as an equalizer of any irregularity in the introduction of the coagulant, will, if of a capacity exceeding three or four hours' supply, in a measure, guard against a temporary cessation of the flow of coagulant.

All this has, in the speaker's opinion, kept the mechanical filter abreast with slow sand filtration, and gives it a rank equal to any device or design in present practice.

In regard to controllers, the speaker believes that a device of this kind in some form or other always has been and is, to-day, an essential part of any mechanical filter; existing, as it may, in a lack of head and, consequently, enforced slow rate of filtration, or cramping of the outlet valve, or a fixed orifice, or an automatic mechanical device especially designed for this purpose, some means should be provided in a complete filter for controlling or preventing an excess rate of discharge after washing.

Mr. Weston. ROBERT SPURR WESTON, ASSOC. M. AM. SOC. C. E., Boston, Mass.—It is fortunate that such excellent papers have been presented, papers noteworthy both for clearness and for the completeness of the information contained therein. The selection of writers has caused the field of water purification to be well covered. Dr. Kemna, as all know, has been foremost among European investigators in showing that filtration is closely connected with biology, and that the problems of the sand layer are literally living ones; Mr. Pennink of Amsterdam has demonstrated how supplies may be obtained from the slowly moving ground waters of the Dutch dunes without causing an inland flow of sea water, and has also shown that this supply can be freed from the iron and organic matter dissolved from the deposits of the Rhine Delta by the dune water; M. Bechmann has been instrumental in doing away with the unhappy notices—not to drink the Seine water without first boiling it—which formerly

were frequently noticed by visitors to Paris; Mr. Hazen, building upon the foundation of the best European practice, has classified and defined its structure and has been one of the chief factors in the development of the present American art. Mr. Weston.

Perhaps one fact has not been emphasized enough, namely, the increased interest in public hygienic matters, especially among physicians, teachers and engineers, classes of professional men to which the people look for guidance and information. This increased development of interest, among the laity also, has, among other things, permitted the collection of vital statistics, has promoted a great number of analytical and other scientific and sanitary investigations, giving data of great value for future use.

In considering the feasibility of adopting any source of supply, it seems to the speaker that one criterion, in addition to the chemical and bacteriological analyses of water, should be taken into consideration, namely, the appearance of the water. It is well known that many people will not drink a water which is not pleasing to the eye and taste, no matter how free from pollution it may be. In its place they will use spring and well waters, many of them of unknown or doubtful history. In studying this point, the speaker selected a number of American cities, the water supplies of which he knew to be unpolluted (from the standpoint of our present knowledge), and divided them into three classes, according to his personal taste, namely, perfect, agreeable and disagreeable; "perfect" waters being those which had no turbidity, and no odor, color, or taste; "agreeable," those which had only slight turbidity, odor, color, or taste; while "disagreeable" included those waters which had either objectionable turbidity, or unpleasant odor, color, or taste. At the same time an assistant computed independently the average typhoid fever death rates in those cities. As a result, it was found that the perfect water was associated with a typhoid fever death rate of 15, the agreeable water with a rate of 17, and the disagreeable water with a rate of 25 in 100 000 living. Furthermore, no connection could be observed between the social characters of the populations of these various cities and the typhoid fever death rates.

In making a study previous to recommending any source of water supply, all engineers, all sanitarians also, generally recognize the necessity of recommending only those surface waters which have been purified either by long storage in reservoirs or by filtration. It is to be hoped that in a few years more the disagreeable waters will be included in the category of those necessary to be purified. The accomplishment of this end will be marked by the disappearance of the venders of promiscuous spring waters from the streets of cities.

The subject of double filtration brings up the old problem of

Mr. Weston. adapting the method of purification to the needs of the particular locality. As a rule, the purification plants in Germany have had to treat comparatively clear waters. The water of the Weser River at Bremen is more or less turbid, and it is largely because of the inadequacy of single filtration in such cases that double filtration has been found necessary. In some other German cities which purify turbid water, Breslau, for example, the tendency is toward the abandonment of filters and the purification of ground water.

Has not the preliminary treatment of the water prior to filtration been overlooked? In the United States, the question which would be raised in designing a plant to meet similar conditions would be whether or not sedimentation basins with or without coagulation, or some other form of preliminary treatment, for example, the scrubber used at Philadelphia, would be less expensive and fully as efficient, when the final product is taken into account, as Herr Goetze's system of double filtration, as practiced at Bremen. The speaker's recollection is that the sedimentation basins at Bremen are very small, too small to be of material service in the removal of turbidity.

Prof. Williams. GARDNER S. WILLIAMS, M. AM. SOC. C. E., Ann Arbor, Mich.—In the matter of improvements to the details of filters, the speaker would add a few words to the discussion already presented. First, as to the strainer arrangement, the tendency seems to be, at present, to distribute the strainers more uniformly over the bottom of the bed, and so return to a fairly close approximation to one of the earlier types of filters which had for a time been almost wholly superseded. In a filter recently designed by the speaker, the strainers were composed of brass plates running the full width of the beds, in gutters or grooves, 6 in. apart, the plates being perforated with $\frac{3}{32}$-in. holes, about $\frac{1}{4}$ in. apart, for a width of about 1 in. throughout their entire length. The gutters, which were 4 in. deep, were filled with carefully screened gravel, and there appears no reason why a larger orifice might not have been used if desired.

As to the rate controller, this device seems more necessary with slow sand filters than with the so-called American type, but if it is not used with the latter a device for automatically regulating the application of the coagulant must be provided. For the latter purpose, the speaker has connected a tank, in which the solution of coagulant was kept at a constant elevation, with reference to the water in the settling basin, to a contraction in the raw-water main. Any increase of velocity in the main increases materially that through the contraction and causes a reduction of the pressure there when more liquid flows in from the tank, the increased quantity being proportional to the increased flow in the main.

Another feature of the development of the American filter is the

increased period of coagulation, which has been gradually extended until, in some plants, it is as much as 8 hr., and in the treatment of waters containing coarse sediment, it has been found desirable to give them a preliminary period of sedimentation before adding the coagulant. Prof. Williams.

Regarding the relations of pure water to the public health, there is a side which has not been discussed as yet. Just as the human organism gradually accustoms itself to taking arsenic, strychnine and other poisons, and becomes immune to their effects, so it appears to minimize itself against the water-borne infections when continuously using a moderately impure water which gradually grows worse. Therefore, if one who has been accustomed to a pure and wholesome water is to travel from place to place, he runs a greater risk of incurring disease than one who is regularly using an impure supply. Some of the most serious epidemics of water-borne diseases have been among communities where there were present a large number of temporary residents who were uninured to the particular water supply, as is always the case in college towns, where the students frequently suffer from water-borne diseases that do not appreciably affect the native inhabitants. So, until pure water is to be had everywhere, it is, perhaps, not an unmitigated blessing to have it anywhere.

RUDOLPH HERING, M. AM. SOC. C. E., New York City.—Mr. Hazen's paper is an excellent one, and brings the subject up to date in better form and more comprehensively than the speaker has seen elsewhere. There is one point on which the speaker wishes to comment, namely, that no reference is made to double filtration, such as is practiced in Bremen, and to its application in the United States. Of course this process has its limitations, and there are probably very few places here where it could be successfully applied. But in view of the apparent completeness of Mr. Hazen's paper, it seems to the speaker that some reference might be appropriate. Mr. Hering.

F. L. FULLER, M. AM. SOC. C. E., Boston, Mass.—In addition to the list of cities and towns of considerable size having ground-water supplies, as given in Mr. Le Conte's discussion, the following table showing towns in Massachusetts of over 5 000 population, so supplied, as taken from the last report of the State Board of Health, may be of interest. Mr. Fuller.

Such supplies are usually very satisfactory, and when quantity and quality comply with established requirements, they receive the approval of the State Board of Health, in preference to surface water supplies, said approval being necessary before a source is adopted. It may be said in passing that Massachusetts has more ground-water supplies than any other New England State. Ground water as contrasted with surface water is of practically uniform

Mr. Fuller. temperature during the entire year,and requires no artificial filtration, having already undergone that process. It is free from the unpleasant tastes and odors often found in surface waters, due to the growth and decay of algæ and microscopic organisms.

Most surface waters require artificial filtration, which, to be effective, must be conducted by skilled attendants, with constant care and vigilance.

CITIES AND TOWNS IN MASSACHUSETTS, OF 5 000 POPULATION AND OVER, SUPPLIED WITH GROUND WATER.

	Population in 1902.	Average daily consumption, in gallons.	Average daily consumption per inhabitant, in gallons.
Amesbury	9 268	403 000	43
Attleborough	12 553	433 000	34
Bridgewater and East Bridgewater	9 331	187 000	20
Brookline	21 443	1 961 000	91
Deadham	7 555	675 000	89
Framingham	12 018	420 000	35
Hyde Park	13 811	949 000	69
Lowell	99 210	5 729 000	58
Marblehead	7 547	484 000	64
Methuen	8 240	333 000	40
Middleborough	6 963	241 000	35
Milford and Hopdale	14 714	791 000	54*
Natick	9 758	404 000	41
Newton	35 986	1 927 000	54
North Attleborough	7 523	296 000	39
Reading	5 070	146 000	29
Waltham	24 523	2 435 000	99
Ware	8 508	342 000	40
Webster	9 206	341 000	37
Wellesley	5 409	257 000	48
Winchendon	5 205	96 000	18

* Some filtered river water used.

Mr. Wall. E. E. WALL, ESQ., St. Louis, Mo.*—The method of clarifying and purifying the water supply of St. Louis is one of chemical purification, a development of the old Clark process with the additional use of ferrous sulphate. Laboratory experiments on the action of ferrous sulphate and lime were begun in November, 1903, but it was not until about April 1st, 1904, that it was possible to test the value of these agents for clarification and purification.

Sulphate of iron and lime had been successfully used as coagulating agents in connection with the use of mechanical filters at Quincy, Ill., and Lorain, Ohio. At these places, these agents were used simply as coagulants, both the sediment and coagulant being caught on the filters. A comparatively large quantity of sulphate of iron was used and only a small quantity of lime, the lime being

* Principal Asst. Engr., Waterworks Extension, St. Louis, Mo.

introduced as lime-water, carrying about 70 gr. of lime per gal. of solution. This produced a quick coagulation, all the lime introduced being taken up by the reaction of the sulphate of iron, and the free carbonic acid in the raw water acting on the free lime. After a great deal of experimenting and study, it was found that an exceedingly clear and pure water could be produced from the raw water by adding a sufficient quantity of lime, not only to combine both with the ferrous sulphate added and the carbonic acid in the raw water, but also to convert the bi-carbonate of lime and magnesia in the raw water to normal carbonate of lime and hydrate of magnesia, both of which would be precipitated, thereby materially softening the water. After having satisfactorily tested these reactions, the problem was then resolved into devising means of practically applying these reagents to the water supply of the city at as small a cost as possible, and with no interference with the existing order of things. To attempt to apply the lime in the form of lime-water was at once seen to be impracticable because of the enormous quantity which would have to be manufactured daily. Some 10 000 000 gal. of lime-water would be required every day, and to supply this would mean the construction of large reservoirs with an extensive plant for constantly agitating the solution. The question of using milk of lime, carrying 5 000 to 8 000 gr. of lime per gal. of liquid, was taken up, and finally a very simple and inexpensive method of producing an even flow of milk of lime of practically constant strength was designed and built. The lime is weighed and dumped every five minutes into tanks supplied with hot water (about 120° fahr.), which slakes the lime very rapidly. The solution of milk of lime is kept in constant motion in the tanks by revolving rakes, the milk of lime being drawn off through pipes, 2 ft. above the bottom of the tanks. This gives a continuous flow of milk of lime of constant strength so long as the quantity and quality of the water treated remains constant. Whenever the quantity of the water being treated is increased or diminished, the weight of the charge of lime is changed accordingly; should the quality of the water change, requiring a greater or less quantity of lime for treatment, the weight of lime added every five minutes is correspondingly increased or diminished; the flow of hot water into the tanks is constant, so that the strength of the milk-of-lime solution varies only as conditions change. Mr. Wall.

The sulphate of iron is handled in practically the same manner as the lime, except that only cold water is used to dissolve the crystals, and no stirring apparatus is necessary for the tanks. The solution of ferrous sulphate is introduced into the raw water before it passes through the low-service pumps, and the milk of lime is introduced after the water leaves these pumps.

Mr. Wall. The water after receiving the lime flows by gravity to the settling basins, six in number, each being 400 by 670 by 15 ft. deep. These basins have the dividing walls cut down so that water can be pumped into the basin at either end and the intervening basins filled and supplied over the dividing walls. Usually the basins are operated in series, the water flowing in one of the end basins, and through all the basins, and being drawn from the sixth and last basin. These basins will hold approximately 180 000 000 gal., and usually the water in the third basin is almost as clear as in the sixth. A very large percentage of the suspended matter, perhaps 80%, is precipitated before the water leaves the first basin.

The precipitation of the suspended matter with the coagulant carries down nearly all the bacteria. The City Bacteriologist has made weekly determinations of the number of bacteria per cubic centimeter in the raw and the treated water. His reports show the average percentage of reduction for each month, as follows:

April,	1904	86%
May,	"	93%
June,	"	96%
July,	"	98.75%
August,	"	95%

His highest percentage of removal on any one determination was 99.66%, although there have been quite a number of cultures made in the Water Department Laboratory, which failed to show any colonies after 48 hr., and even longer, while the raw water of the same dates showed 2 000 to 22 000 per cu. cm.

The maximum quantity of lime and iron used per gallon of water pumped has been 9 gr. of lime and 3 gr. of iron. This was for a short time only, while the raw water was very muddy. The minimum quantities used were 5 gr. of lime and ¼ gr. of iron per gal. The average for five months' operation of the coagulating plant was 5 gr. of lime and 1½ gr. of iron per gal. During this time, the suspended matter in the raw water varied between 1 200 and 4 000 parts per million, and in the treated water from 10 to 40 parts per million.

At times there has been found a slight caustic alkalinity in the water in the settling basins, which disappears before it reaches the consumer. Usually none is to be found at the intake of the high-service pumps.

The time of sedimentation is undetermined so far, owing to the fact that, on account of construction work and cleaning, the basins have been used as circumstances permitted, and not altogether as they were intended to be used. It has not been possible to use them

at one time, in any continuous way, long enough to make any determinate experiments, as to the average time the water remained in the basins. Mr. Wall.

JOHN F. WIXFORD, ESQ., St. Louis, Mo.*—Immediately upon the assumption of his duties as Chemist for the St. Louis Water Department, on October 1st, 1903, the speaker began experiments in the Water-Works Laboratory to determine the efficiency of the various brands of aluminum sulphate as clarifiers. Very soon after this, parallel experiments were conducted by a method using ferrous sulphate and hydrate of lime in such quantities only as are sufficient to change the ferrous sulphate to hydroxide after both chemicals were added to the water. Mr. Wixford.

These experiments showed that the efficiency in clarification was decidedly in favor of the method using ferrous sulphate; but it was found very difficult to eliminate all the iron by simple sedimentation, and any appreciable quantity of iron left in the water would be decidedly objectionable, because of the very great staining power of the compounds of iron.

However, a sudden rise of the Mississippi River, in the early part of January, 1904, made things look very dark for all the coagulating processes used in the experiments, because of the great quantities of comparatively expensive coagulants required.

In the latter part of January, 1904, the speaker, experimenting in his own private laboratory, found that by adding lime-water in considerable quantity to crystal-clear filtered Mississippi River water an abundant white precipitate was obtained, possessing very marked coagulating power. He also found that if sufficient lime-water was added even the dissolved coloring matter was removed from the water.

These experiments, coupled with his knowledge of the dissolved constituents of the water, and with facts learned by experimenting with calcium hydrate upon dissolved magnesia salts and soluble silicates, made it very evident that by the addition of sufficient calcium hydrate to the water, it would be possible to convert the very constituents of the water itself into a coagulating material sufficient at any and all times to clarify the water by simple sedimentation, and, at the same time, to remove all the calcium hydrate added. This has been verified by experiments beyond all possibility of doubt, but it was found that considerable time and almost perfect rest were necessary to allow the sedimentation to take place.

The following experiment was next made. A small quantity of ferrous sulphate was added to crystal-clear filtered Mississippi River water, and then calcium hydrate was added in quantity sufficient, not only to combine with all the ferrous sulphate previously added,

* Chemist, Water Dept., St. Louis, Mo.

Mr. Wixford. but also sufficient to change the dissolved constituents of the water itself to insoluble coagulating compounds. The result of this experiment was a coagulating precipitate which settled very rapidly, and which had the remarkable advantage of having a white color with no staining power whatever. This experiment proved, and further experiments substantiated, the fact that very efficient iron coagulants might be used in water purification, and, at the same time, have all their objectionable staining power removed. It was found also in this experiment that after a reasonable time allowed for sedimentation the water became crystal clear and carried not the slightest trace of iron in either suspension or solution.

When this same treatment was applied to the raw Mississippi River water, a wonderful coagulation was made perceptible, and, in a comparatively short time of quiet settling, the water was crystal clear. When applied to the worst water the Mississippi could produce and at the worst season of the year, it was found that by a judicious addition of the chemicals, results could be obtained in 3 min., which would compare favorably with results obtained by 72 hr. of plain sedimentation of the same water.

These facts, seconded by additional experiments, soon removed all doubts from the minds of the Engineer-in-Charge and the Water Commissioner. They were finally convinced that a wonderful and practical, as well as simple, process of water purification was close at hand.

Suitable methods for adding the chemicals to the water next occupied the speaker's attention. From the very nature of the case, it will be seen that any such method must of necessity be simple, safe, practical and entirely at the control of the operator. The speaker always carried in his mind, in these studies, the process used in feeding coal to the fires under the boilers at the Water-Works. Year in, year out, night and day, without a break, this process goes on, and upon it depends the proper working of all the complicated machinery of the Water Department. The following experiment was made. Equal and carefully weighed quantities of ferrous sulphate in the shape of crystals were thrown at regular intervals of time into a small test tube, and a tiny continuous stream of cold water was kept running into the bottom of this tube and overflowing at the top. After continuing this process for some time, it was noticed that a volume of crystals had accumulated at the bottom of the tube, and this volume remained practically constant. The running water, in passing through this volume, was taking into solution during each interval of time a quantity of ferrous sulphate practically equal to the quantity of this salt added at the beginning of the interval. A working model embodying this principle of constant volume was immediately devised by using a

common wooden water-pail, introducing an overflow pipe near the top and a rosette of horizontal jets at the bottom for supplying the continuous stream of cold water. Repeated series of experiments were made with this model, and it was demonstrated that a practically uniform solution of ferrous sulphate could be obtained by adding equal weights of ferrous sulphate every 5 min. By increasing the flow of water and also the weights of ferrous sulphate added, it was found that a nearly uniform solution of ferrous sulphate could be obtained with this small model, sufficient for the treatment of the water supply of a small city. These experiments banished the idea of introducing large tanks for making ferrous sulphate solutions of a definite strength. Mr. Wixford.

A method for obtaining milk of lime in a continuous and uniform quantity next occupied the speaker's attention. Having determined that lime will slake rapidly in flowing water having a temperature of 125° fahr., the idea presented itself that by slaking equal weights of lime at regular intervals in a vessel through which hot water was flowing, there would be generated an emulsion of calcium hydrate having a definite bulk and consistency, from which, if kept in agitation, the water running through the vessel would carry away just as much calcium hydrate during an interval as was made by slaking an equivalent quantity of lime added during an equal interval. The small model used for generating the ferrous sulphate solution was used in the first experiments embodying this idea. It was found, however, that because of insufficient agitation the lime began to cake in the bottom of the vessel, thus defeating the idea in view. Air was run into the vessel with the hot water, but sufficient agitation could not be obtained by this means to prevent the lime from caking. Another model was then built, using a round iron tank about 30 in. high and 18 in. wide. An overflow was provided about 4 in. from the top of this tank, and a mechanical stirrer was inserted. This stirrer consisted of a hollow vertical shaft, revolving upon a projecting pin at the bottom and in a journal at the top. About 6 in. from the bottom, hollow cross-arms were attached to this shaft and to the cross-arms. Coiled springs extending to the bottom were attached and served as rakes to prevent any caking action of the lime, and, at the same time, possessed the power of riding over the portions of unslaked lime added at regular intervals. The revolving motion was imparted to this stirrer by bevel gears connected by a shaft and pulley to a small Pelton waterwheel. The hot water entered through the vertical shaft and issued from jets in the cross-arms. Repeated series of experiments were made with this model, and it was demonstrated that a practically uniform emulsion of calcium hydrate could be obtained by adding equal weights of unslaked lime every five minutes. By increasing

Mr. Wixford. the flow of water, regulating the speed of the stirrer, and increasing the weight of lime added, it was found that a nearly uniform emulsion of calcium hydrate could be obtained with this model sufficient to treat about 6 000 000 gal. of water, using a ratio of 6 gr. of lime per gal. of water treated.

During February, 1904, sufficient information in regard to the efficiency of the chemical process of coagulation and sufficient data in regard to the methods of adding the chemicals were at hand to convince the authorities of the feasibility of at once building a coagulating plant with ample capacity to treat the whole water supply of the city.

Through the zealous activity of the Engineering Corps of the Water Department, this plant, embodying all the principles of the experimental models, was ready and set in operation on March 22d, 1904, and has been in continuous operation ever since that date.

On the very day the plant was started, the river began to rise, and the process had to contend with the worst possible water the Mississippi can furnish. A marked improvement, however, in the city's water supply was plainly observed from the very start, and, after a short period of experience with the process, the city was receiving water which, from a chemical standpoint, was purer than filtered Mississippi water. An immense reduction in the number of bacteria has also been brought about. To-day, operating upon water not so difficult to handle, the process is furnishing the city with crystal-clear water of very excellent quality.

In the beginning, both chemicals were added to the water before it entered the pumps, provision being made, however, that the water should receive the ferrous sulphate solution somewhat before the milk of lime. The very considerable crystallization consequent on this process, however, made itself manifest in coating the valve chambers of the pumps, and this scheme had to be abandoned.

In the present plan, the ferrous sulphate solution is added to the water before it enters the pumps, and the milk of lime, after dilution with cold water, is forced around and beyond the pumps into the delivery well. Here the calcium hydrate becomes thoroughly mixed with the water already treated with ferrous sulphate, and, from this point, the water treated with both the ferrous sulphate and calcium hydrate flows by gravity into the large settling basins of the Water Department, where the chemical reactions are completed, and the crystallization, coagulation and sedimentation take place.

In order to understand this process, it must be borne in mind that the Mississippi River water holds in solution a complex mixture of compounds. Only a portion of these have a bearing upon the process. This portion consists essentially of free carbon dioxide,

calcium bi-carbonate, magnesium bi-carbonate, silicates and coloring Mr. Wixford.
principles. All these compounds are capable of forming insoluble precipitates with calcium hydrate, and some of these precipitates have a decided coagulating power.

Upon the addition of ferrous sulphate to the Mississippi River water, it combines with a portion of the calcium bi-carbonate in solution according to the following reaction:

$FeSO_4 + 7H_2O$ +	$CaH_2(CO_3)$ =	$CaSO_4$ +	$FeH_2(CO_3)_2$ +	$7H_2O$
Ferrous Sulphate.	Calcium Bi-carbonate.	Calcium Sulphate.	Ferrous Bi-carbonate.	Water.

Now, both the products of this reaction, namely, calcium sulphate ($CaSO_4$) and ferrous bi-carbonate ($FeH_2(CO_3)_2$), remain in solution, and, consequently, after treatment with ferrous sulphate, the water is in the condition of ordinary chalybeate waters, which also contain iron in solution as ferrous bi-carbonate. There is no more danger in drinking the water at this stage of the treatment than there is in drinking the chalybeate ground waters which are used as sources of water supply by many people living in our bottom lands. There is no possibility of any undecomposed ferrous sulphate remaining in the water, even at this stage of the treatment, because the quantity of bi-carbonates in the water is sufficient to decompose many times more ferrous sulphate than it is practical to add.

The calcium sulphate formed in the above reaction increases the permanent hardness of the water slightly, but has no further bearing upon the process. However, the important compounds which do have a bearing upon it after the treatment with ferrous sulphate are the ferrous bi-carbonate introduced; the original carbon dioxide; a portion of the calcium bi-carbonate not acted upon by the ferrous sulphate; and all the original bi-carbonate of magnesia; the silicates and coloring principles. Hence when the calcium hydrate is added, the following reactions take place:

$FeH_2(CO_3)_2$ Ferrous Bi-carbonite.	+	$2Ca(OH)_2$ Calcium Hydrate.	=	$Fe(OH)_2$ Ferrous Hydrate.	+	$2CaCO_3$ Calcium Carbonate.	+	$2H_2O$ Water.
CO_2 Carbon Dioxide.	+	$Ca(OH)_2$ Calcium Hydrate.	=	$CaCO_3$ Calcium Carbonate.	+	H_2O Water.		
$CaH_2(CO_3)_2$ Calcium Bi-carbonate.	+	$Ca(OH)_2$ Calcium Hydrate.	=	$2CaCO_3$ Calcium Carbonate.	+	$2H_2O$ Water.		
$MgH_2(CO_3)_2$ Magnesium Bi-carbonate.	+	$2Ca(OH)_2$ Calcium Hydrate.	=	$Mg(OH)_2$ Magnesium Hydrate.	+	$CaCO_3$ Calcium Carbonate.	+	$2H_2O$ Water.

Mr. Wixford. In addition to these reactions, others occur by the action of calcium hydrate upon the silicates and coloring principles, producing insoluble calcium compounds, but the exact formulæ are not known. One other reaction, however, occurs. The ferrous hydrate formed as above, by hydration and oxidation at the expense of the free oxygen in the water, is changed to ferric hydrate according to the following equation:

$$\underset{\text{Ferrous Hydrate.}}{2Fe(OH)_2} + \underset{\text{Water}}{H_2O} + \underset{\text{Oxygen.}}{O} = \underset{\text{Ferric Hydrate.}}{Fe_2(OH)_6}$$

A study of the above reactions will reveal the fact that not only has all the calcium hydrate added been changed to an insoluble shape, but that it has changed all the iron salt previously added, as well as the whole group of compounds, before mentioned as dissolved in the water, to insoluble compounds.

It should be noticed here that it requires only one equivalent of calcium hydrate to change the free carbon dioxide and the calcium bi-carbonate to insoluble normal carbonate of calcium, but that it requires two equivalents of calcium hydrate to change either the ferrous bi-carbonate, or the magnesium bi-carbonate to insoluble hydrates. This is specially to be observed in the case of magnesium bi-carbonate, because one equivalent of calcium hydrate would only change this compound to the normal carbonate of magnesia which is soluble to a considerable extent, whereas two equivalents of calcium hydrate will change the bi-carbonate of magnesia to practically insoluble hydrate of magnesia.

To determine the quantities of chemicals to be added to the water beforehand, the following simple method is used. A series of about eight jars are filled with the raw water. To these limewater is added in respective quantities, representing ratios of lime from 1 to 8 gr. per gal. of water treated. After stirring and allowing an hour or two for sedimentation, a decided break will be noticed in the series. Beyond this break in the jars which contain the higher ratios of lime, the water clears rapidly, while below this point, in the jars which contain the lower ratios of lime, very little clarification is apparent. The jar containing the lowest ratio of lime in which the clarification is decided contains the ratio of lime to be used. The ferrous sulphate is determined altogether by the rapidity of sedimentation desired. It has been found that the ratio of lime to be added ranges between 4 and 7 gr. per gal. of water, and the ferrous sulphate to be used ranges between ½ and 3 gr. per gal. of water.

To sum up then, the rationale of this process is that by first introducing a solution of ferrous sulphate into the water, there is obtained not only the specific action of this salt upon the organic

matter both in suspension and solution, but by direct combination with the bi-carbonates dissolved in the water ferrous bi-carbonate is formed. This compound remains in solution, and thus becomes evenly distributed throughout the whole water, and this ferrous bi-carbonate, upon the subsequent addition of calcium hydrate, is converted into an insoluble coagulating hydroxide of iron. Now, when sufficient calcium hydrate is added to combine with the compounds before mentioned, originally dissolved in the water, an abundant white precipitate is formed; all of which has a decided crystallizing power, and a large proportion of which has besides a definite coagulating action, especially the magnesium hydrate. Furthermore, the insoluble coagulating hydroxide derived from the ferrous sulphate first added, and the insoluble coagulating compounds derived from the reaction of calcium hydrate upon compounds originally dissolved in the water enwrap the suspended matter of the water, both mineral and organic, including bacteria, and then collect it into aggregations. These aggregations, by the interlocking of the suspended matter and by the crystallization upon them of the abundant insoluble precipitates formed by the reaction of calcium hydrate upon the compounds originally dissolved in the water, have their weight increased to such an extent that they settle very rapidly, leaving the water clear and purer by far in every sense of the word than the original water and without introducing a process of filtration. Mr. Wixford.

From a perusal of what has been written, it will be seen that the chemical reactions involving coagulation and crystallization all take place in the large settling basins which are placed between the two pumping systems. In these settling basins, the suspended coagulated aggregations furnish ample surface for crystallization, and the time of sedimentation can be made more than sufficient for all the reactions to be completed. Thus all danger of incrustation after the water leaves the settling basins is entirely eliminated, and this has been proved beyond a doubt by a trial of over seven months' duration.

The corroding influences of a water are essentially due to free carbonic acid, or other acids, and dissolved oxygen. A study of the reactions will at once reveal the fact that one of these factors, namely, free carbonic acid, or other acid, has been entirely eliminated. There still remains in the water, however, some dissolved oxygen which has a slight corroding action upon iron pipes, but this action is less than would be the case of the natural water after simple filtration, and far less than that of any alum-treated water. The action upon lead pipes is eliminated because there is always left in the finished water more calcium sulphate than was present in the raw water, and besides some calcium carbonate always re-

Mr. Wixford. mains because the normal calcium carbonate is not absolutely insoluble.

The slightly caustic alkalinity, as shown by silver nitrate, is due to the fact that magnesium hydrate, one of the coagulants generated in the water, is not entirely insoluble, and the slight quantity remaining dissolved gives the silver nitrate reaction.

This process has been in use now for over seven months and has given entire satisfaction to the mass of the community. In a slightly modified form, the process may be adapted to almost any water supply. With properly constructed settling basins and sufficient time for sedimentation, this process will yield a purer water, at less expense, than any scheme involving filtration.

Mr. Fuller. GEORGE W. FULLER, M. AM. SOC. C. E., New York City.—Mr. Hazen's paper is an excellent account of the substantial progress which has been made in the field of municipal water purification during the past decade.

The paper treats in a sound and terse manner the essential steps in the progress which has been made, and it refers judiciously and conservatively to the present status of a number of the more important features now pressing for attention in the line of possible modifications and improvements.

Speaking generally, there are no good reasons for believing that the leading principles of present practice will not continue as a working basis for many years to come. Unquestionably the future will see improvements of importance with reference to the preparation of muddy waters for filtration; the filters themselves will be constructed in a more simple and durable manner as to some of the detailed parts; the plants, as a whole, will probably present a more attractive appearance than in the case of some of the earlier filters; and devices to improve and make more automatic the operation of both sand and mechanical filters will become a more prominent feature of future filters than the present ones. Indeed the latter class of improvements is characteristic of many of the filters now building.

To attempt to discuss the way in which current filter designs differ from those of three to five years ago involves too much technical detail to find a place properly in a general discussion like the present one.

In the United States, not only are engineers fully awake to the necessity of building plants in which all reasonable facilities are afforded for high-grade and efficient operation, but it is worthy of note at this time that practically without exception the influence of those engineers who give most attention to filter questions is an important factor in advancing, for sanitary reasons, operating procedures which will eliminate unsatisfactory results such as were obtained from time to time from the earlier filters.

The paper refers to mechanical filters of recent design as equal in hygienic efficiency to the newer sand filters as shown by laboratory data, at the same time pointing out that their equality has not been clearly demonstrated by the test as to the effect which the water produces upon the health of the people who drink it. As a general proposition this is true, but a detailed inquiry as to recent and current data will show that during the past three years or so there has been a decided change in the effect produced by mechanical filtration upon the health of communities in which this type of filter is located. At York, Pa., Lorain, Ohio, Binghamton, N. Y., and several other places, typhoid fever death rates, which were previously very high, have become as low as in the case of American cities using either ground-water or water obtained by most carefully conducted sand filtration. With these, the recently constructed filters at Little Falls, N. J., Ithaca, N. Y., and Watertown, N. Y., and others, it is safe to say that there are more mechanical filter plants in the United States now being carefully operated than there are sand filter plants. Of the total number of plants of each type, the proportion of each giving satisfactory results of course still shows mechanical filtration in an unfavorable light, due to weaknesses of construction and operation in the plants earliest built. This is particularly due to faulty operation, as there is no doubt about some of the old mechanical filters being capable of giving quite satisfactory hygienic results, although they are clumsy affairs in some respects. Mr. Fuller.

Very significant, and valuable for reference, are the data presented by Mr. Hazen showing the hygienic benefit derived from filtration as shown by vital statistics, and especially interesting is the important point cited as to the marked improvement in the general death rate in those cities in which filtration has been adopted, reductions comparing favorably with those in cities which have changed their sources of supply from polluted rivers to either ground-water or upland waters from very sparsely populated areas. There seems to be no doubt as a general proposition that the statistics show clearly and logically the features to which Mr. Hazen draws attention. In some particular cases there are presumably factors at work, the significance of which is not now appreciated, and which obscure to a considerable degree the influence of filtration upon vital statistics. They are the exception, however, not the rule. They suggest, furthermore, that a more critical and exhaustive study than hitherto has been the case should be made of all the various factors affecting vital statistics associated with water-borne diseases.

Allen Hazen, M. Am. Soc. C. E., New York City. (By letter.)—The writer is particularly gratified at the extended and adequate Mr. Hazen.

Mr. Hazen. discussion of his subject, reflecting the progress of the art in foreign countries and dealing with many developments in the United States.

The statement in M. Bechmann's paper as to the advances made in filtration in France is most gratifying, and to some extent surprising. The use of filtered river water by the City of Paris, which for many years has prided itself on the exclusive use of spring water, is one of the most notable hygienic developments of the decade, and is in contrast with the effort to substitute ground-water for filtered river water in certain German cities, mentioned in the discussions by Messrs. Le Conte and Kemna.

The statement in Dr. Kemna's paper regarding European ideas as to quality of water supplies, and as to the means used for reaching the desired results, is authoritative, and shows an interest in the subject and a practical advancement in the art which is quite as rapid as that taking place in the United States.

The treatment of water, even experimentally, by extremely powerful oxidizing agents, such as ozone, compounds of chlorine and oxygen, and the more recently described "ferrochlore," mentioned in the papers of Messrs. Kemna and Bechmann, and in the discussions of Messrs. Howatson and Whipple, has thus far been confined almost entirely to Europe. The field is an interesting one, and will be watched closely. It is to be hoped that opportunities will be afforded to test these processes thoroughly in this country by experiments comparable to those which, ten years ago, served to establish the fundamental facts regarding mechanical filtration.

It is to be hoped that something substantial will be gained from these processes; but it must be remembered that, although new processes of water treatment have been proposed with regularity and frequency, the proportion of such new processes leaving a permanent impression upon the art of water purification is comparatively small.

Of this group of processes, the ozone treatment has been most discussed, but even in Europe it has been tried on hardly more than an experimental scale, and certainly not in such a way as to give an outsider an intelligent idea of the cost which would be involved in a large installation, although such figures as have come out indicate a cost many times greater than that mentioned by Mr. Le Conte.

The first official publication in the United States in regard to the use of copper sulphate for treating waters, which is mentioned by Mr. Whipple, came after the writer's paper was prepared. It is only fair to state, however, that the use of copper in treating water was recommended in Germany by Kröhnke eleven years before Dr. Moore of the United States Department of Agriculture suggested its use, and its advantages in treating waters containing typhoid or

cholera germs were pointed out; but the objections to the use of a substance commonly supposed to be poisonous prevented its practical application in Germany. Dr. Moore's work related primarily to killing the algæ and only incidentally to the removal of bacteria, which was the primary object of Kröhnke. In this country, few processes have ever found such wide application within a correspondingly short time after their announcement. This is largely due to the cheapness and simplicity of the procedure. It is too early to forecast the future of this process; but it seems clear that its field is a somewhat limited one, and that it will not to any substantial extent take the place of filters and other processes of purification now in use. It seems rather to have a field of its own, and a field where the older processes had decided limitations. Mr. Hazen.

Mr. Whipple's data as to the utility of soft water and the advantages of softening are most important. When these matters become better understood, softening plants will be extensively used, particularly for the treatment of ground-waters, the use of which is commended by Messrs. Pennink, Le Conte and F. L. Fuller.

Ground-waters, particularly those coming from formations containing lime, are apt to be so hard as to detract from their use for domestic purposes. In Mr. Le Conte's tables, some cities are included where certainly the ground-water does not form the bulk of the supply, as, for instance, in Brooklyn; and in some of the German cities mentioned, although the conditions for getting ground-water are relatively favorable, the use of filtered river water is very far from being abandoned.

The results given in Mr. Pennink's paper upon the flows of fresh and salt water in gravel deposits near the sea would seem to be capable of advantageous application in this country; as, for instance, upon Long Island, where there is a large demand for water to supply Brooklyn and other cities, and where the salt water is so near the wells that the question is often raised as to how much water can be drawn from them permanently without drawing sea water and thereby ultimately destroying the supply.

Preliminary filtration is mentioned by M. Bechmann in his paper as having originated in Paris, and its application in the United States is discussed at some length by Mr. Maignen. A closely allied, but somewhat different, subject, namely, double filtration, is suggested by Mr. Hering.

There seems to be no doubt that the results accomplished by sedimentation basins can be reached more quickly and with much more compact apparatus by preliminary filters or scrubbers. The evidence is by no means as clear that it will be generally safe to increase the rate of the final filters, or that materially better results can be obtained from them. It is to be remembered that sand

Mr. Hazen. filters have been repeatedly operated under favorable conditions with success, at rates considerably higher than those usually regarded as safe in practice. In other words, the usual design has a considerable factor of safety. The fact that good results are obtained at rates higher than the usual ones in connection with a particular appliance is by no means conclusive evidence that the favorable results are due to that appliance; for there is a likelihood that they would have been obtained even though the particular appliance had not been used.

There seems to be some ground for the thought that preliminary filters or sedimentation basins remove precisely those particles which would be most easily and certainly removed by the filters, and that they fail to remove those particles which are capable of passing entirely through the sand filters and producing turbid effluents; and so far as this is the case, it is not apparent that preliminary filters will essentially change the limiting conditions in the final filters, or the character of the effluents obtained from them. Preliminary treatment reduces the rate of clogging in the final filter and prolongs the period between cleanings; and if this is not accompanied by too great an increase of the depth of sand which must be removed at each cleaning (by reason of the greater penetrating power of the finer sediment), the advantage secured in this way may be important. It should be noted, however, that an important function of sedimentation basins in many cases is to store water, equalizing the operation of the works, and allowing the intake to be closed sometimes during periods of excessive turbidity of the raw water. These uses of a sedimentation basin are sometimes more important than its direct use of removing the sediment from the water; and in these particulars preliminary filtration seems incapable of serving as a substitute.

The desirability of securing water of satisfactory physical character, mentioned by Mr. R. S. Weston, is a very important matter, and one that must always be kept in mind. Nevertheless the public is always ready to co-operate in maintaining this standard, and it is less likely to be overlooked for this reason.

In the importance of securing intelligent and careful operation of filters, the writer thoroughly agrees with Mr. Chester, and the knowledge which has been gained in the last decade, and which now allows filters to be operated far more intelligently and more certainly than was formerly the case, is a substantial element in the progress attained, and it is to be counted, perhaps, as important as the improvements in design which have been made.

It cannot be doubted that it is a physical possibility to operate some of the mechanical filter plants constructed more than ten years ago so as to produce satisfactory effluents. Nevertheless, it

is equally true that very few, if any, of these plants were so operated in the first years after they were built, and before scientific information regarding the process was secured. Mr. Hazen.

The sterilization of water by heat, mentioned by M. Bechmann, seems to have received much more attention in France than in this country. It is interesting to recall that the water supplied to the workmen at the World's Columbian Exposition at Chicago before the Fair opened in 1893, was treated by this process with most satisfactory results. It was also used extensively in connection with the cholera epidemic in Hamburg in 1892. This method of producing a water, unquestionably free from infection, whatever its source, and at a reasonable cost, would seem to have an important field where water of undoubted purity is required promptly and only in moderate quantity. For instance, such water distributed for drinking purposes during a typhoid epidemic where the public water supply is known to be the cause of the trouble might be most beneficial, and it would seem that the apparatus for sterilizing water in this way could be made portable and ready for immediate use in such cases.

The writer agrees with Messrs. Jordan and G. W. Fuller that it is most important that further study be made of the effect of water supply upon other diseases than typhoid fever. The statistics certainly indicate a much wider influence of water supply upon public health than has been generally admitted; and it would seem as if studies might be made to ascertain the facts more definitely.

The fact that those who are used to a bad water supply are less apt to be hurt by it than those who are used to good water, mentioned by Mr. Williams, has long been recognized; but it can hardly serve as an excuse for the continued use of an impure source.

Any person familiar with the public water supply of St. Louis in the past, and who saw during the Congress the comparatively clear water flowing from the faucets, must have been deeply impressed with the beneficial results of the treatment described by Messrs. Wall and Wixford as in use at the St. Louis works. The method of applying the chemicals is very ingenious and seems to be particularly adapted to use in large works.

The process used, which is a combined treatment of ferrous sulphate and lime, is one which has been generally used for treating sewage for many years. For instance, it was, and the writer believes still is, used for treating the sewage of London before discharging into the Thames, and the sewage of Worcester, Mass., and Providence, R. I., is treated upon this plan. The chemistry of the process was investigated at the Lawrence Experiment Station of the Massachusetts State Board of Health in 1889, and the principles of successful treatment then determined have stood the test

Mr. Hazen. of time and are as directly applicable to the conditions at St. Louis as they were to the treatment of sewage at Lawrence; and the results obtained at St. Louis, including bacterial removal, seem to be quite in line with the indications of the Lawrence experiments.

While the improvement in the quality of the water at St. Louis is striking, and the advantages of the process, as compared with no treatment at all, are very great, the results must be considered as falling far short of those which could be obtained if a thorough system of filtration was made a part of the process, and the procedure must, therefore, be regarded as provisional, and not as a permanent solution of the water problem in that city.

There is a particularly interesting point in connection with the St. Louis treatment. Lime is used to such an extent that the water is partially softened. An inevitable result of this is that the effluent contains a certain amount of normal calcium carbonate which is not combined with the carbonic acid which usually accompanies it in natural waters. It is usually found that this excess of lime deposits slowly upon everything with which the water comes in contact, and it has been considered necessary in connection with softening plants or other treatments of water using lime in considerable quantity to recarbonate the water. That is to say, it has been regarded as necessary to resupply the amount of carbonic acid ordinarily present in natural waters, and which was removed by the lime used. This part of the process has not been supplied at St. Louis, and it will be interesting to see if a water containing so much lime in proportion to the carbonic acid present can be supplied continuously to a city with satisfactory results. If it should prove feasible to do this, the problem of water softening will be made materially easier of solution.

Dr. Kemna. DR. ADOLPH KEMNA, Antwerp, Belgium.* (By letter.)—The writer will limit his final discussion to the following subjects.

Sulphate of Copper.—An old experiment of Raulin showed that one of the common moulds, *Penicillium glaucum,* refused to grow in a nutrient solution contained in a silver dish, although not the slightest trace of silver could be detected by chemical analysis. Many years later, Naegeli found that several metallic salts in very weak solution had the same effect, and, to that action of extremely diluted solutions, he gave the name of oligodynomy. Some light on the chemical process of the action of silver salts may be gathered from the researches of Loew and Bokorny, showing that living protoplasm contains aldehydic compounds.

From the information published, the following facts seem pretty well established:

* Manager, Antwerp Water-Works Company.

1.—Small doses of $CuSO_4$ can prevent the development of or destroy blue algæ; it is much to be regretted that, in all cases, a competent botanist was not called in to determine exactly the species dealt with. Dr. Kemna.

2.—The quantity being small, the cost is not prohibitive.

3.—The solubility of the salt facilitates its use greatly.

4.—The salt is decomposed and its quantity too small to justify any fear of poisoning.

At the Waelhem Filter Station for the Antwerp supply, the writer succeeded, during the hot summer of 1904, in preventing taste, by using sulphate of alumina and especially by cleaning the filters when they developed blue algæ (that year mainly, *Alphanisomenon*), irrespective of the loss of head. But this means more frequent cleaning, increased expenditure and the disadvantage of doing away with the filters during the period of their highest bacterial efficiency. On reading the reports of sulphate of copper, it occurred to the writer that the substance would be very useful, if applied at the proper time, namely, before the acme of pollution by blue algæ, not as a cure, but as a preventive. If growth has already developed to a great extent, the wholesale destruction of the organisms must impart a bad taste to the water; this has been found to be the case in some American experiments, where for a short time the use of sulphate increased the bad taste of the water.

But one possible drawback suggests itself immediately to the writer. The filtering organisms, to which the chemical purification of the water is due, are the diatoms; and there is no need of nor any advantage in destroying these. However, all organisms are not the same, and there are probably differences in their sensitiveness to reagents. From their structure, a silicious investing carapace, and from their greater resistance to general causes of destruction, the writer concludes that there may be a possibility of keeping under the blue algæ, without interfering too much with the diatoms. Mr. Whipple's discussion is especially interesting. He states that such a difference really exists, and he looks upon it as a difficulty, because he probably has in mind his old foe, *Asterionella,* a floating diatom. The writer considers this difference as rather favorable, and intends to work the filters of the Antwerp Water-Works on this line during the summer of 1905.

Hardness.—It appears that hard waters found no advocate at the Congress. From a chemical point of view, dissolved lime salts are an impurity; for most industrial purposes, they are a great trouble. Mr. Whipple's calculations as to the quantity of soap wasted are interesting, giving as they do actual figures, without the exaggerations indulged in by some writers. The physiological benefit of hard waters has never been proved, and seems more than

Dr. Kemna. doubtful. Soft water is a great advantage, and can generally be had from rivers.

Mr. Maignen says that sulphate of alumina, by turning the bicarbonate of lime into sulphate, makes the water harder than before. This statement is not quite correct; the permanent hardness is increased by the same amount that the temporary hardness is diminished, so that the total hardness remains the same.

Mechanical Filters.—One of the drawbacks of the older pressure filters, apart from the complication of machinery, is the possible redissolving of the precipitate under the influence of pressure. From experiments made in 1888, the writer has concluded that iron oxide is redissolved when free carbonic acid is present. Bi-carbonates decompose by dissociation, and the rate of dissociation is inversely proportional to the pressure. This circumstance renders pressure filters impossible with chalybeate ground-waters as they are now used in Germany.

Sand Filters.—The main point of sand filters is their striking hygienic efficiency, even when only moderate care is given to their working. Practically speaking, the results, as to health, were equally good before bacteriology became the ruling consideration. Mr. Howatson's contention that "typhoid and other germs are continually found in the filtered water" is not consistent with facts; on the contrary, the typhoid germ is very rarely found in all waters. To the writer's mind, undue stress is laid in France upon the presence of *coli,* a harmless microbe.

Paris.—M. Bechmann has pointed out some erroneous statements contained in the writer's paper. There has not been a mistake in estimating the yield of some of the springs. But, in his interesting book describing the Paris supply in 1900, he says (page 76) that, in dry periods, the 290 000 cu. m. per 24 hours are reduced to 210 000. In the Montsouris reports (Vol. I, p. 228), for the Avre springs from January to April, 1900, the figures range from 737 liters per second to 1 826. At the meeting of the committee on May 18th, 1900, M. Bechmann admitted, for the Vanne, variations from 1 to 2 or 3, and for the Avre from 1 to 3 or 4. Practically it is unimportant now whether this was foreseen or not; and it was not the writer's intention to throw any blame on the past or present engineers for that point. The main fact is that there was not water enough; that the deficiency was made good with raw river water up to 1899; and that, in July, 1900, the supply was cut off during the night, and also in July, 1904.

It is a well-known fact that the temporary supply of river water was restricted to some quarters, and that the inhabitants were warned; and the writer remembers that a vote of some official body ordered this kind of supply to be restricted to rich quarters.

The Montsouris reports trace several epidemics to one or other of the springs, and if this condition can be considered satisfactory, it is only in comparison with a former situation which was still worse. Dr. Kemna.

Belgrand, no doubt, acted for the best, and according to the restricted knowledge of his time. M. Bechmann has inherited a situation for which he is not responsible, and it is very praiseworthy of him that on all occasions he defends his predecessors. But for all that, if Paris had followed the example of London and used filtered Seine water instead of springs as a supply, while the water would not have been so cool, it would have been much less dangerous, and the plant would have been much less expensive.

M. Bechmann, Paris, France.* (By letter.)—The question of purification of water for domestic purposes has been well treated by Mr. Hazen. The writer is much interested in the communication of M. Pennink, which relates to a special case, and he most cordially supports the conclusions of Dr. Kemna on the general progress in the course of the last decade. He would have no observations to present if the last-mentioned paper, speaking incidentally of the water service in Paris, had not been somewhat in error in regard to several points. M. Bechmann.

There was no miscalculation in regard to the quantity of water obtained from the Dhuis and the Vanne, which were the only services in use at the period when it was common to substitute river water during some weeks in the summer. These sources have never ceased to furnish at all times the volume of water which was estimated originally; and if there was a scarcity in spring water for a short time, this was due not to any diminution in the quantity of water available, but to a considerable increase in the daily consumption at these times, easily explained by the agreeable freshness of this water.

In the same way, the statement of Dr. Kemna in regard to the action of the Municipal Council of Paris is incorrect, because there has been no distinction whatever made between the rich quarters and the poor quarters in the distribution of water. These two statements in the report of our colleague are incorrect.

In regard to the term "gross mistake," which is applied to the use of spring water from calcareous formations, resting upon the proposition of Belgrand in 1855, at a time long before the discovery of microbes and the recent developments in hydrology, it is sufficient to recall that the use of these waters in Paris was accompanied by a considerable reduction in the mortality from typhoid fever. Thus for the five years, 1881-85, the first for which a certain classification of deaths is available, the mortality from typhoid fever reached 8.8

*Ingénieur en Chef des Ponts et Chaussées, Chef du Service des Eaux et de l'Assainissement de Paris.

M. Bechmann. per 10 000 inhabitants. In the last five years, 1899-1903, notwithstanding a limited typhoid epidemic in 1899, the rate was only 2 per 10 000, the reduction being more than 77%, practically the same figure as that found by Mr. Hazen for the cities where the filtration of drinking water has had the most favorable results.

Further, the gradual transformation of the drinking water of Paris had been effectively commenced long before 1881, namely, in 1862; and if statistics permitted us to go back so far, the showing would certainly have been much more favorable. One is thus able to affirm positively that securing water from the calcareous formations of the Parisian basin, aside from the fact that they have supplied the population of Paris with water clear and fresh, which has been appreciated, has had a salutary effect from the standpoint of public health.

The writer does not care to discuss the subject further in a general way, as such consideration should only have a place in papers presented before an International Engineering Congress. But he cannot refrain from answering statements developed at great length by Mr. Maignen, in relation to the installation made by him in 1896-97 at Saint-Maur, near Paris. It will suffice, in order to show that these statements are entirely inexact, to state that since August 17th, 1897, M. Humblot ordered that the tests be stopped on the following October 1st; that a report of M. Méker, of December 14th, 1897, established the fact that the installation had not satisfied the stipulated conditions, neither as regards the quantity of water treated, nor as to its quality as relates to its microbe-containing capacity, nor yet as regards the net cost; and that finally an order of the Prefect of the Seine, dated March 13th, 1899, forced Mr. Maignen's company to remove the installation.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

LOCOMOTIVES AND OTHER ROLLING STOCK.

Congress Paper No. 52.

AMERICAN LOCOMOTIVES.

By William Forsyth, M. Am. Soc. M. E., Chicago, Ill., U. S. A.

Congress Paper No. 53.

ROLLING STOCK IN FRANCE.

By Edouard Sauvage, Ingénieur en Chef des Mines,
Professeur à l'Ecole des Mines, France.

Congress Paper No. 54.

THE BALANCED COMPOUND LOCOMOTIVE.

By S. M. Vauclain, M. Am. Soc. M. E., Philadelphia, Pa., U. S. A.

Discussion on the Subject by:

W. F. M. Goss, Lafayette, Ind., U. S. A.
G. R. Henderson, New York City, U. S. A.
A. Mallet, Paris, France.
O. Busse, Copenhagen, Denmark.
Karl P. Dahlström, Stockholm, Sweden.
Henry S. Haines, Detroit, Mich., U. S. A.

Note: Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 52.

LOCOMOTIVES AND OTHER ROLLING STOCK.

AMERICAN LOCOMOTIVES.

By William Forsyth, M. Am. Soc. M. E.

The paper on "American Locomotives," read at the meeting of the International Engineering Congress in Chicago in 1893, was prepared by the late David L. Barnes, M. Am. Soc. C. E., and its title was "Distinctive Features and Advantages of American Locomotive Practice."* It related to a comparison of American locomotives, and their operation, with those in foreign countries, and, as the differences therein described exist largely at the present time, it will not be necessary in this paper to draw similar comparisons. Mr. Barnes' paper gave the principal dimensions and characteristics of American locomotives at that time, and it is the writer's purpose now to show the progress that has been made in locomotive design in the eleven years since that time, and give some account of the present practice in locomotive operation.

While the description of present practice in locomotive design in America may not be of special interest to American engineers, it is thought advisable to make this record of it at the time of another great Exposition, as the dates of these World's Fairs and these International Engineering Congresses, are in many ways convenient points of reference in marking the grand periods of industrial progress. It is hoped, also, that this account may be of interest to

* *Transactions*, Am. Soc. C. E., Vol. XXIX, p. 385.

foreign engineers who are not as familiar with American motive power and rolling stock. The nature of the paper will be better understood when it is remembered that it is written from this standpoint, and largely for the benefit of foreign engineers.

The dimensions of American locomotives in 1893, as given by Mr. Barnes, may be taken as representative of the practice at that time, and the writer has selected from his list those which may be regarded as typical passenger and freight engines, as built in the United States in 1893:

PENNSYLVANIA RAILROAD EIGHT-WHEEL PASSENGER ENGINE.

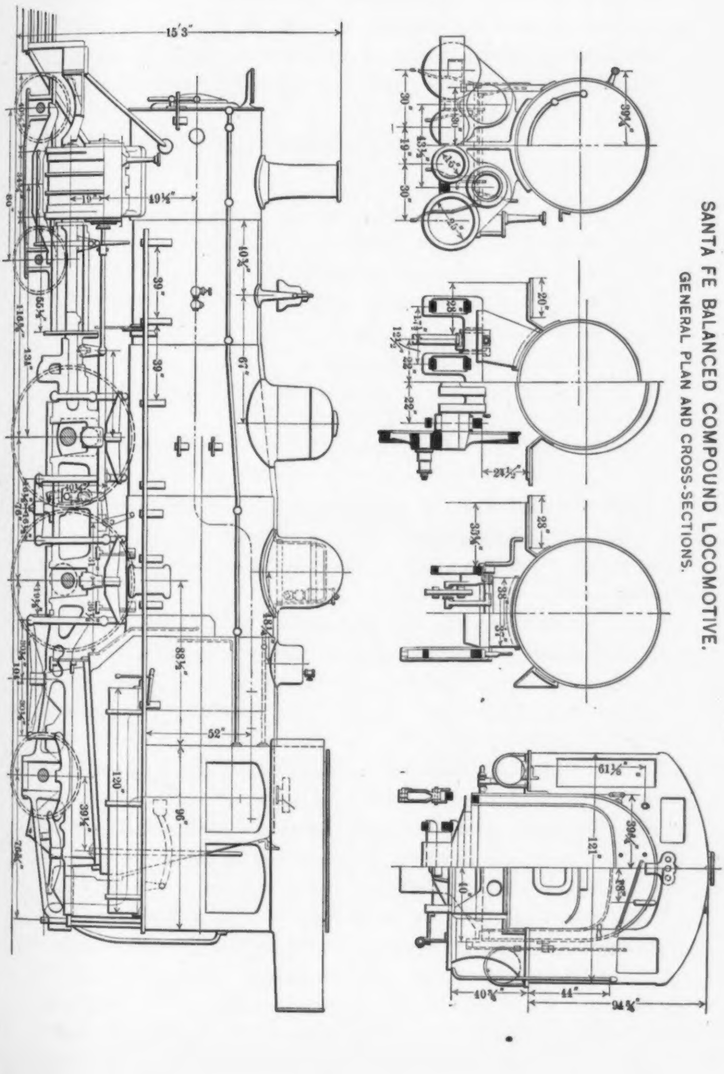
Cylinders	19 by 24 in.;
Diameter of drivers	78 in.;
Total weight of engine	123 000 lb.;
Weight on drivers	81 000 lb.;
Diameter of boiler	58 in.;
Boiler pressure	180 lb.;
Grate surface	26.2 sq. ft.;
Total heating surface	1 672 sq. ft.

LARGE PASSENGER ENGINE 999, EXHIBITED BY THE NEW YORK CENTRAL RAILROAD AT THE WORLD'S FAIR IN 1893.

Cylinders	19 by 24 in.;
Diameter of drivers	84 in.;
Total weight	123 000 lb.;
Weight on drivers	82 200 lb.;
Diameter of boiler	58 in.;
Boiler pressure	180 lb.;
Grate surface	27.3 sq. ft.;
Total heating surface	1 697.5 sq. ft.

FREIGHT CONSOLIDATION, BALTIMORE AND OHIO RAILROAD.

Cylinders	21 by 26 in.;
Diameter of drivers	50 in.;
Total weight	125 000 lb.;
Weight on drivers	113 000 lb.;
Diameter of boiler	55 in.;
Boiler pressure	180 lb.;
Grate surface	28.7 sq. ft.;
Total heating surface	1 584 sq. ft.



SANTA FE BALANCED COMPOUND LOCOMOTIVE.
GENERAL PLAN AND CROSS-SECTIONS.

FIG. 1.

Locomotive Types.

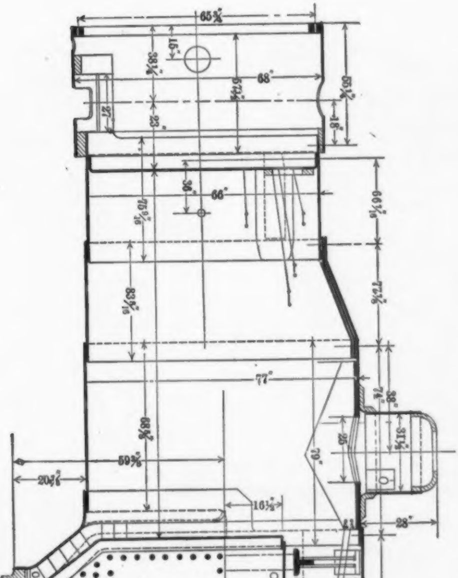
The changes in the wheel arrangement of locomotives have been so numerous that it has been found necessary to designate the different types by figures, which give, first, the number of wheels in the leading truck, then the number of drivers and then the number of wheels in the trailing truck.

Under such a classification the principal types of road engines now in use are as follows:

4—4—0............Eight-wheel, or American type;
2—6—0............Mogul;
4—6—0............Ten-wheel;
2—4—2............Columbia;
4—4—2............Atlantic;
4—6—2............Pacific;
2—8—0............Consolidation;
4—4—0............Mastodon;
2—5—0............Decapod.

Since 1893 the types of passenger locomotives, as distinguished by their wheel arrangement, have completely changed, and the eight-wheel American type, 4—4—0, is no longer built for fast express service.

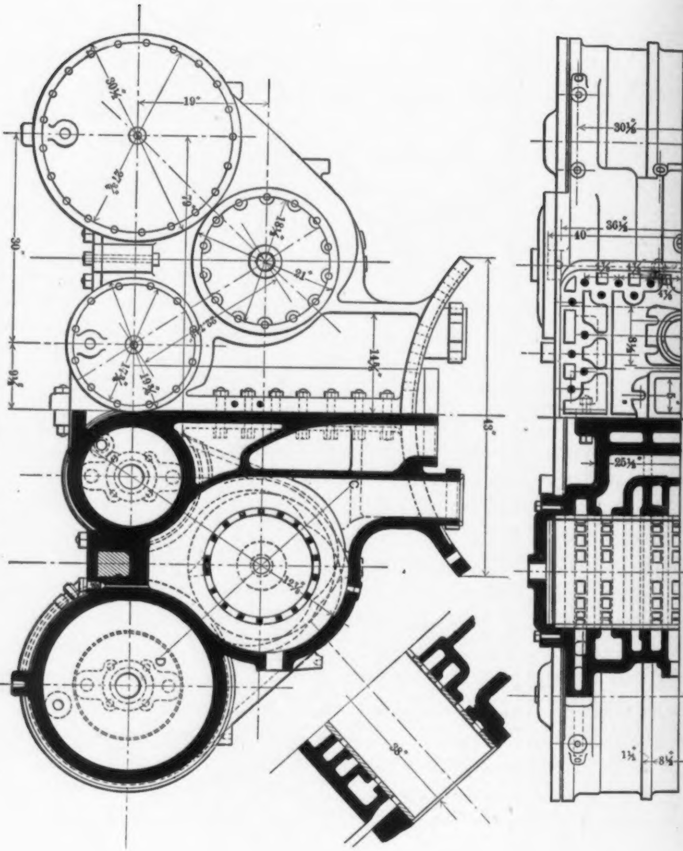
In passenger service, the competition of the different roads advertised itself by offering greater luxury and magnificence in sleeping cars, parlor, buffet and dining cars, of elaborate finish, greater length and greater weight. The length of these cars of modern construction is 70 ft., and their weight 120 000 lb. The number of passengers hauled in a solid vestibuled train made up of such cars is comparatively small, and the weight of train per passenger very great. Such service is necessarily expensive. It is not profitable, and it is probably the most luxurious and most inefficient of any passenger service in the world. Trains of eight to ten of such cars weigh from 400 to 500 tons, and to haul them at average speeds approaching 50 miles per hour required a large increase in the weight and power of the locomotives. It was not possible to arrange a boiler of sufficient capacity on the 4—4—0 American eight-wheel type, and the Columbia, or 2—4—2, was first substituted, as any arrangement with trailing wheels allows a wider fire-



BOILER OF SANTA FE BALANCED COMPOUND LOCOMOTIVE

FIG. 2.

SANTA FE BALANCED COMPOUND LOCOMOTIVE



SIDE ELEVATIONS AND SECTIONS OF CYLINDER.
FIG. 8.

PLATE VI. VOL. LIV. PART D.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
FORSYTH ON
AMERICAN LOCOMOTIVES.

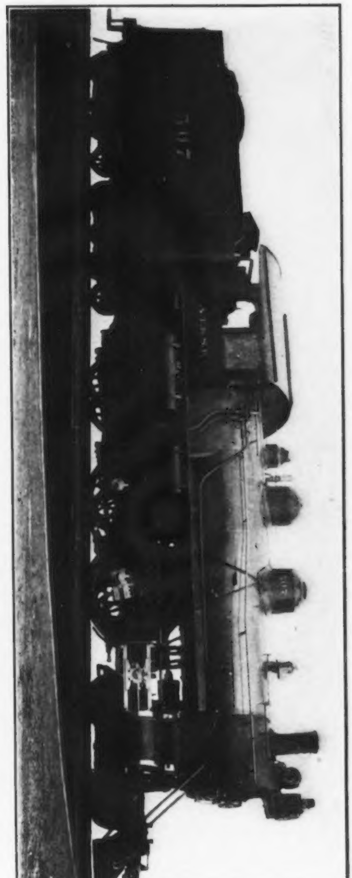


FIG. 1.—SANTA FÉ FOUR-CYLINDER BALANCED COMPOUND LOCOMOTIVE—ATLANTIC TYPE.

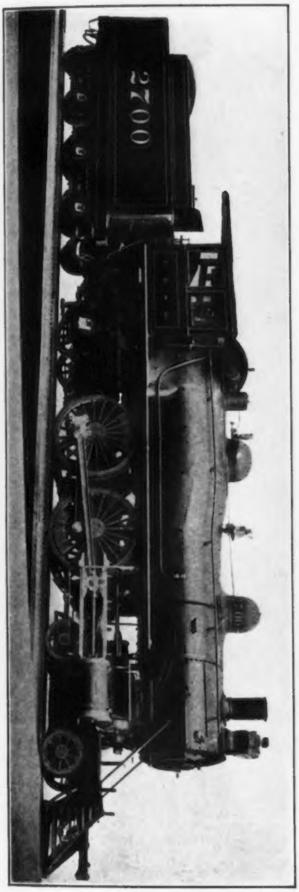
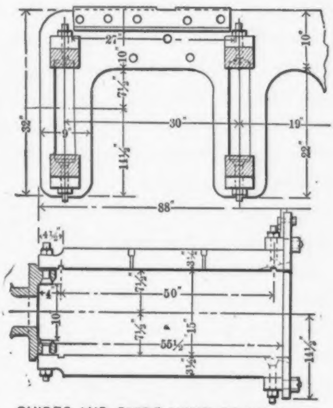


FIG. 2.—FOUR-CYLINDER BALANCED COMPOUND LOCOMOTIVE. CHICAGO, BURLINGTON & QUINCY RAILROAD.

SANTA FE BALANCED COMPOUND LOCOMOTIVE

box to be carried entirely behind the drivers, and also admits a longer boiler barrel. For high speeds it was considered safer to use a four-wheel leading truck, and the best experts on track are of the opinion that the four-wheel truck causes less irregular deflection in the track and roadbed in advance of the drivers than a two-wheel truck, and therefore results in smoother riding and less injury to track. The Atlantic type, 4—4—2, therefore, has become a favorite type of passenger locomotive for express service. It has been built in large numbers in the United States, and is being introduced gradually in England, France and Germany. When still greater power is demanded for passenger service, and a larger boiler is necessary, the Pacific type, 4—6—2, is used, this having six drivers, with the same arrangement of leading and trailing wheels. Locomotives for burning anthracite coal have quite a different appearance from those for bituminous coal, as the wide firebox in the former requires the cab to be placed well forward about the middle of the boiler, and the arrangement of the cab fixtures, the dome and the bell, are not such as to result in a handsome machine.



GUIDES AND GUIDE YOKE OF SANTA FE BALANCED COMPOUND LOCOMOTIVE.

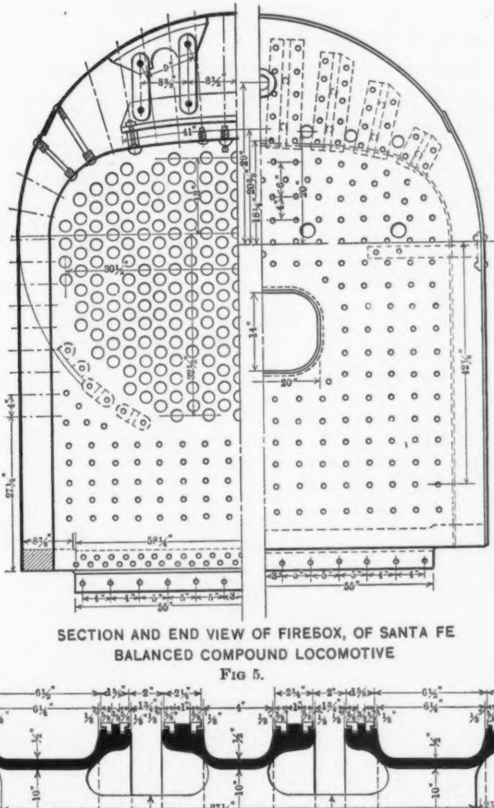
FIG. 4.

FOUR-CYLINDER BALANCED COMPOUNDS.

For medium-weight trains and high speeds, it was desirable to retain the Atlantic type, with only four drivers, but when this type was developed to an extreme size the total weight on the drivers was as great as 100 000 lb., and the weights of the reciprocating parts with simple cylinders were so great that the centrifugal force of the extra weight in the counterbalance increased the pressure on the rail at high speeds to 20 or 30% in excess of the static load. In order to overcome these difficulties, the four-cylinder balanced

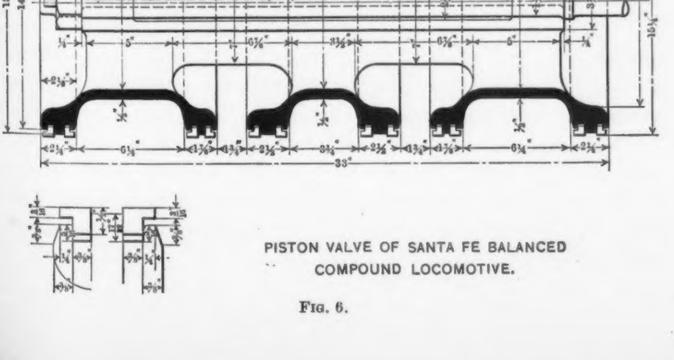
compound was introduced by the Baldwin Company, and first used in regular passenger service by the Santa Fe Railroad in 1903. Four engines of this kind were used on the Santa Fe Railroad in 1903, and, during 1904, forty additional engines were ordered. In this engine, the four cylinders are placed in line laterally, and they are all connected to the front axle, which is cranked. The arrangements of the cranks are such that the reciprocating parts balance each other, and the pressure on the rails is increased very slightly at high speeds. The engines ride very smoothly, and their success is indicated by the large additional order which has been given. In this type, as the force of all four cylinders is transmitted through the crank axle, the stress in that axle must be great, and two of them have cracked in the main rod bearings. In repairing these axles, a 4-in. hole has been bored through the crank portion at the bearing, and a steel pin driven through and riveted. In future work, the cranks will be constructed in this way. A modification of this type, in which the outside cylinders are connected to the rear drivers, has been built by the Baldwin Company for the Chicago, Burlington and Quincy Railroad. In this way the stresses from the cylinders are divided between the two axles. The cylinders are all placed in line laterally, but the piston rod and main rod of the outside cylinder are longer, so as to reach the rear driver.

Another four-cylinder balanced compound passenger engine of the Atlantic type has been designed by Mr. Francis Cole at the Schenectady Locomotive Works for the New York Central Railway. In this engine, the high and low-pressure cylinders are connected to different drivers. The high-pressure cylinders on the inside are placed in advance of the low-pressure cylinders, and they are connected to the front axle, which is cranked. The low-pressure cylinders on the outside are connected to the rear drivers. The four-cylinder engines, by both the Baldwin and the American Locomotive Companies, are operated by the Stephenson link motion, with one link for each pair of cylinders. In the Baldwin (Vauclain) engine, a single valve controls the steam for the high and low-pressure cylinders. In the American Locomotive Company (Cole) four-cylinder engine, there is a piston valve for each cylinder, but the valves for a high and low-pressure cylinder on one side are operated from one valve stem. It may be interesting to compare these arrangements of cylinders, valves, rods and links, with the Von



SECTION AND END VIEW OF FIREBOX, OF SANTA FE BALANCED COMPOUND LOCOMOTIVE

FIG 5.



PISTON VALVE OF SANTA FE BALANCED COMPOUND LOCOMOTIVE.

FIG. 6.

Borries and de Glehn four-cylinder compounds, and the diagrams in Fig. 7 are given for this purpose.

Cole.—High-pressure cylinders inside, but in advance of the smokebox, driving front driving axle. Low-pressure outside, in line with the smokebox, driving rear driving axle. Two piston valves on a single stem serve the steam distribution for each pair of cylinders, and each valve stem is worked from an ordinary link motion.

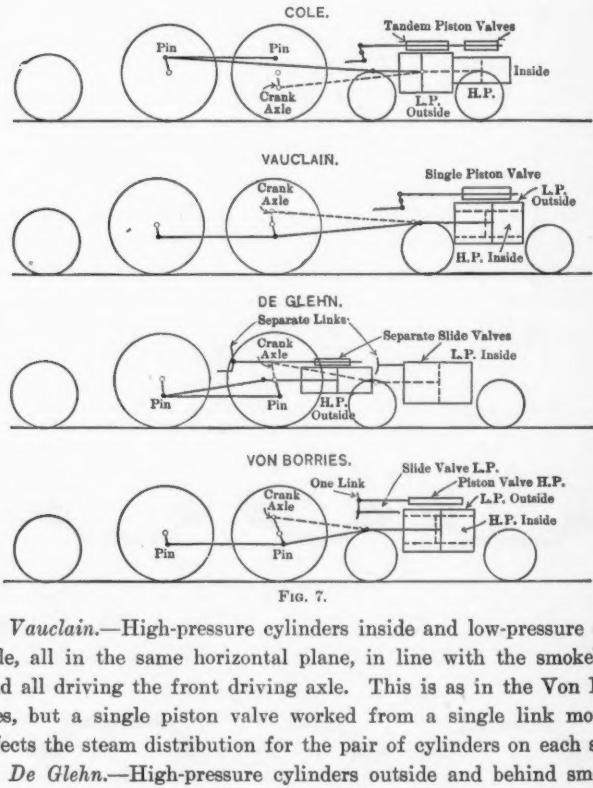


FIG. 7.

Vauclain.—High-pressure cylinders inside and low-pressure outside, all in the same horizontal plane, in line with the smokebox, and all driving the front driving axle. This is as in the Von Borries, but a single piston valve worked from a single link motion effects the steam distribution for the pair of cylinders on each side.

De Glehn.—High-pressure cylinders outside and behind smokebox, driving the rear drivers. Low-pressure cylinders inside, under smokebox, driving crank axle of front drivers. Four separate slide valves and four Walschaert valve gears, allowing independent regulation of the high and low-pressure valves.

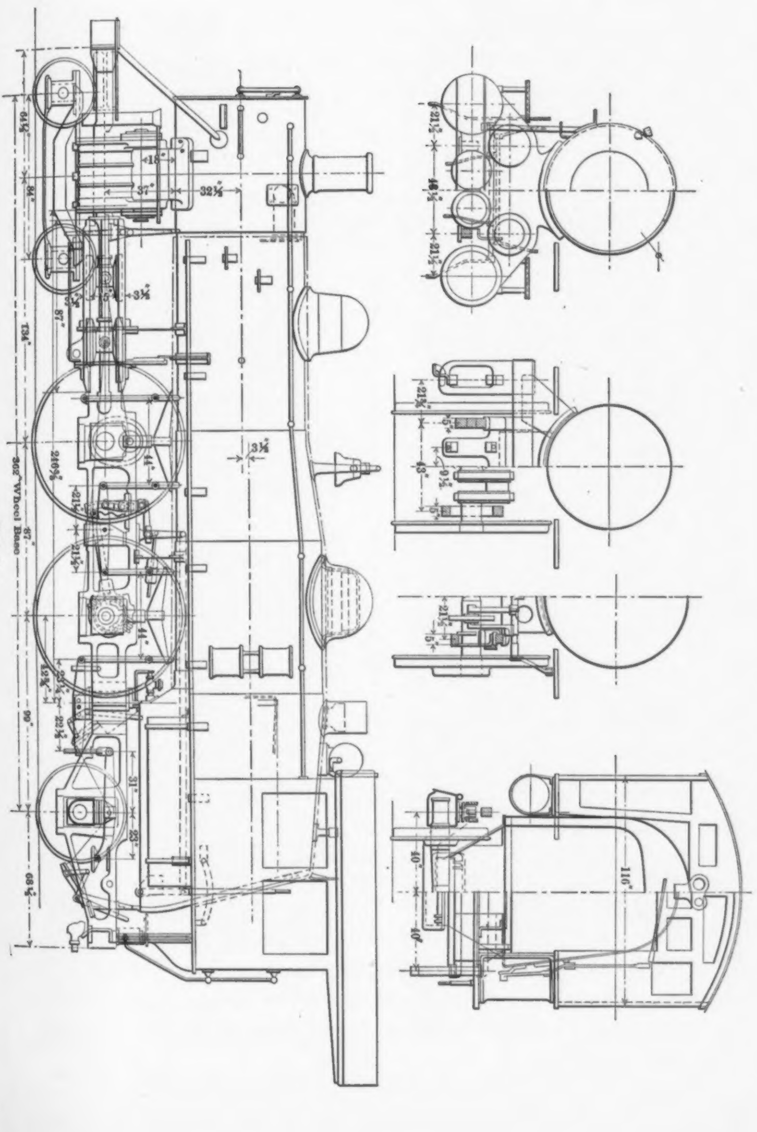


FIG. 8.

VAUCLAIN FOUR-CYLINDER BALANCED COMPOUND PASSENGER LOCOMOTIVE

Von Borries.—High-pressure cylinders inside and low-pressure outside, all in the same horizontal plane, in line with the smokebox, and all driving the front driving axle. Each cylinder has its own valve, but the two valves of each pair of cylinders are worked from

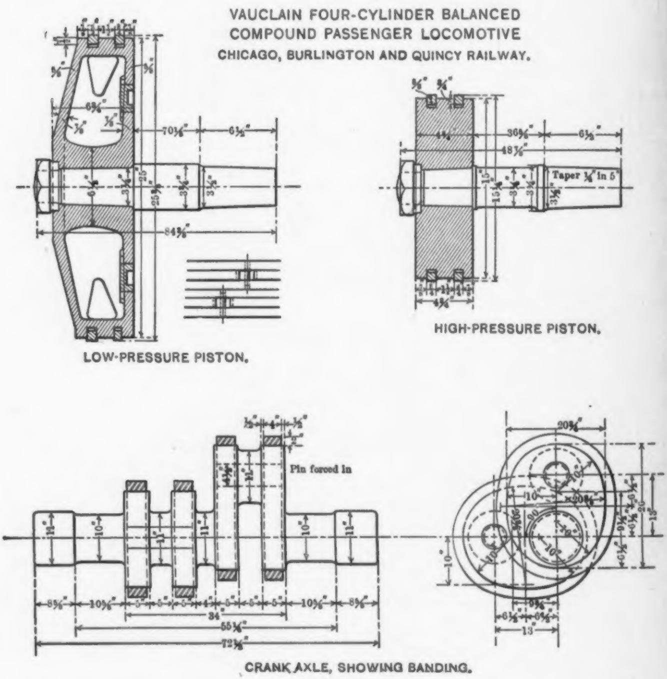


FIG. 9,

a single valve motion of a modified Walschaert type. This arrangement allows of varying the cut-off of the two cylinders, giving different ratios of expansion, which, however, cannot be varied by the engine-man.

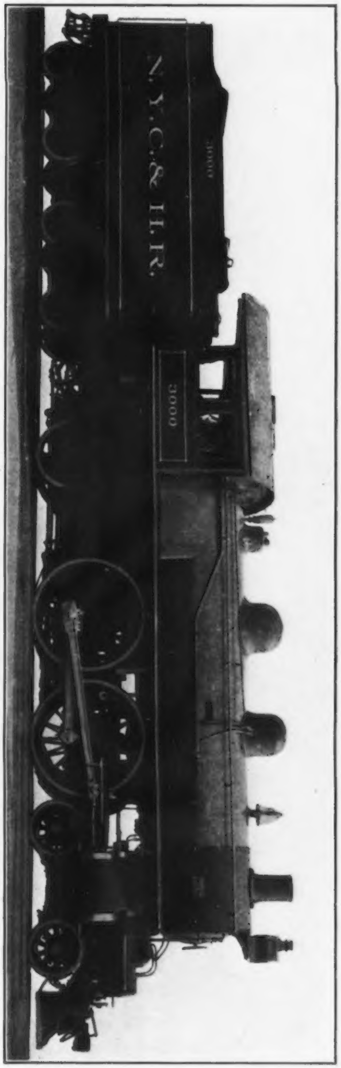


FIG. 1.—COLE DESIGN, FOUR-CYLINDER COMPOUND LOCOMOTIVE, NEW YORK CENTRAL & HUDSON RIVER RAILROAD.

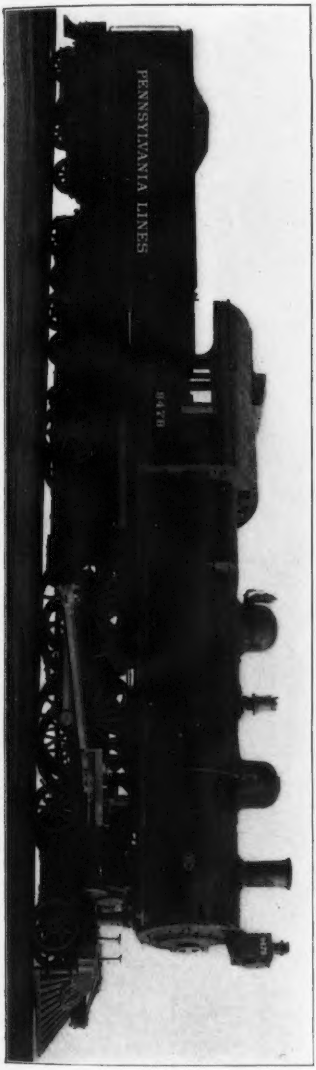


FIG. 2.—ATLANTIC LOCOMOTIVE, CLASS E2A, PENNSYLVANIA LINES.

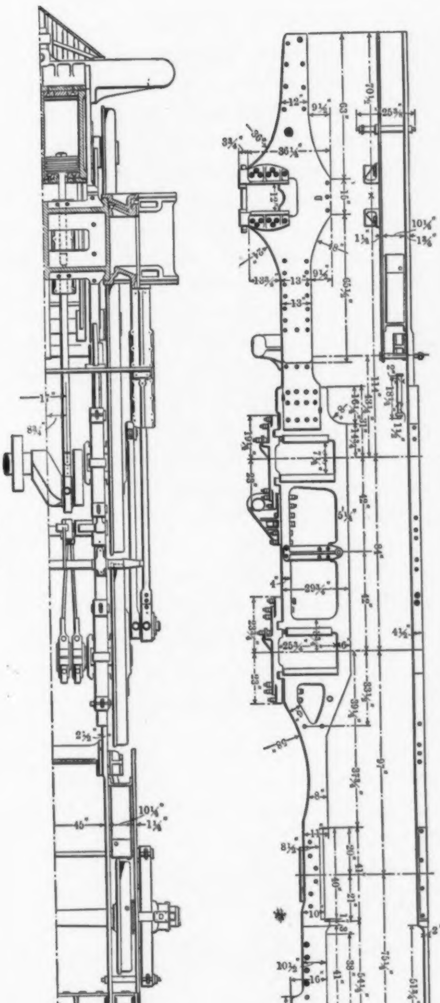


FIG. 10.

FRAME. AND PLAN OF RODS AND RUNNING GEAR. NEW YORK CENTRAL
FOUR-CYLINDER BALANCED COMPOUND LOCOMOTIVE.

Freight Locomotives.

The demand for greater power in freight engines was the result of the introduction of the steel car, which increased the lading of freight cars from the ordinary capacity of 25 and 30 tons to 40 and 50 tons. The draft gear of these cars being entirely of steel and the automatic couplers of cast steel, made it possible to haul large trains of them without danger of breaking in two. The rating of locomotive capacity by the ton tended constantly to increase the trainload to the maximum, and the economy of this method of transportation, as compared with the old method, which gauged the train simply by a given number of cars, resulted in a demand for larger engines and greater tractive power. The consolidation type of freight engine, 2—8—0, which was first used in the United States in 1866, is still the prevailing type, as it can be built with a boiler large enough for the heaviest through freight service. For mountain grades, when pushing engines are required, the Decapod and Mastodon types are often used, and a twelve-wheel Mallet articulated compound engine has been built during 1904 at the Schenectady Works for pushing on heavy grades.

The simple consolidation freight locomotive of the Lake Shore and Michigan Southern Railroad represents good modern American practice at the present time. The dimensions of this engine are as follows:

Cylinders	23 by 30 in.;
Diameter of drivers	57 in.;
Total weight	235 400 lb.;
Weight on drivers	207 000 lb.;
Diameter of boiler	80 in.;
Boiler pressure	200 lb.;
Grate surface	55 sq. ft.;
Total heating surface	3 957 sq. ft.

The boiler in this engine is proportioned for burning bituminous coal. In a consolidation engine, for the Central Railroad of New Jersey, designed for burning fine anthracite coal, the large firebox, which is 123 in. long and 97 in. wide inside, requires the cab to be placed ahead of it, which changes the appearance of the locomotive, giving

PLATE VIII. VOL. LIV. PART D.
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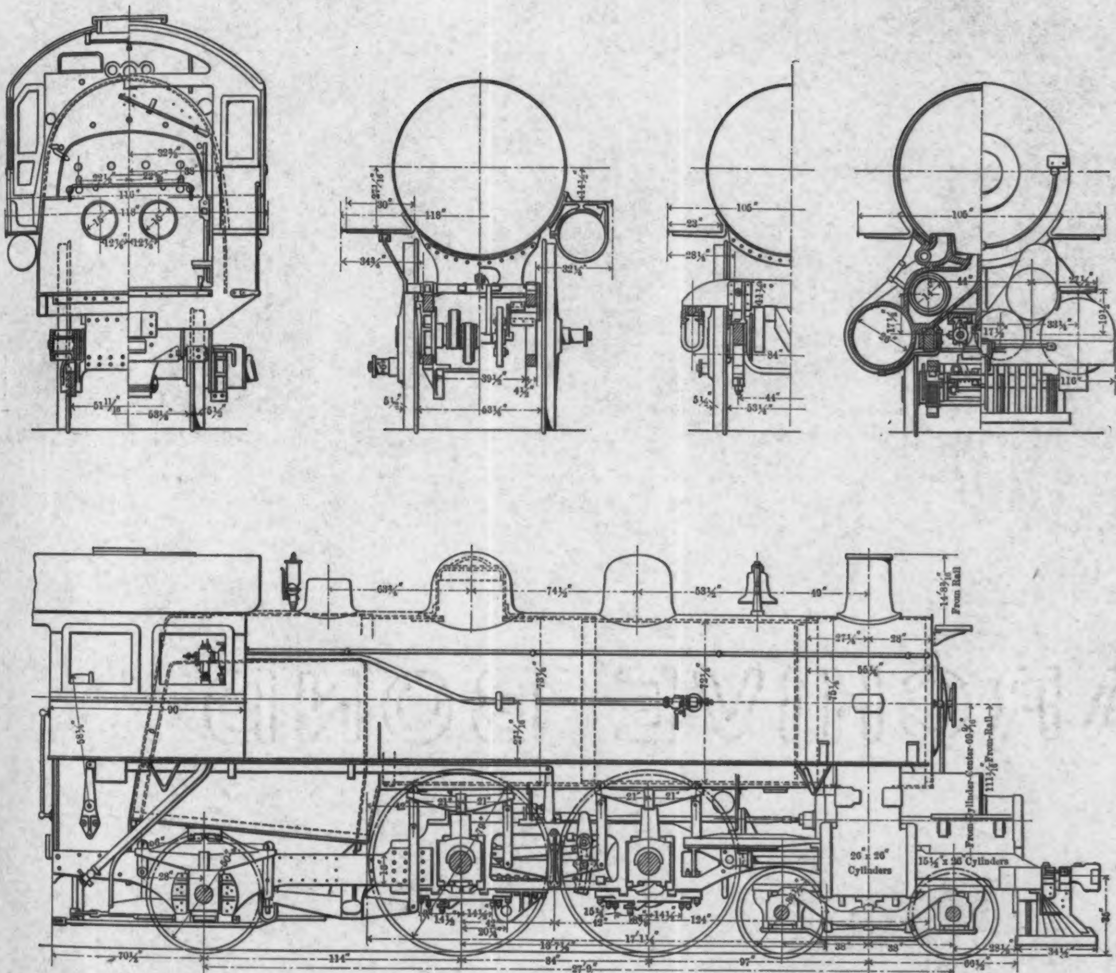
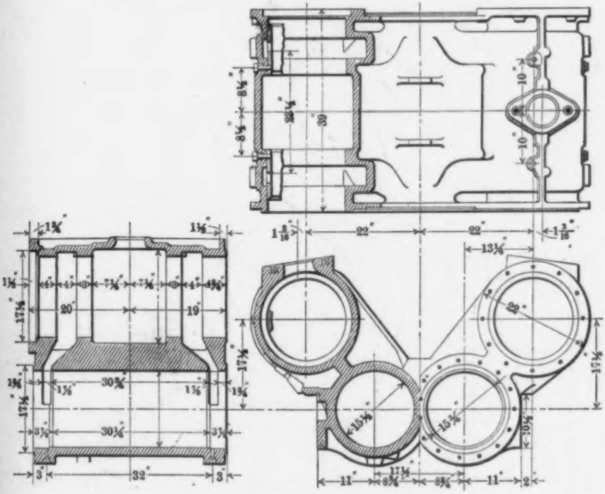
AMERICAN LOCOMOTIVES.

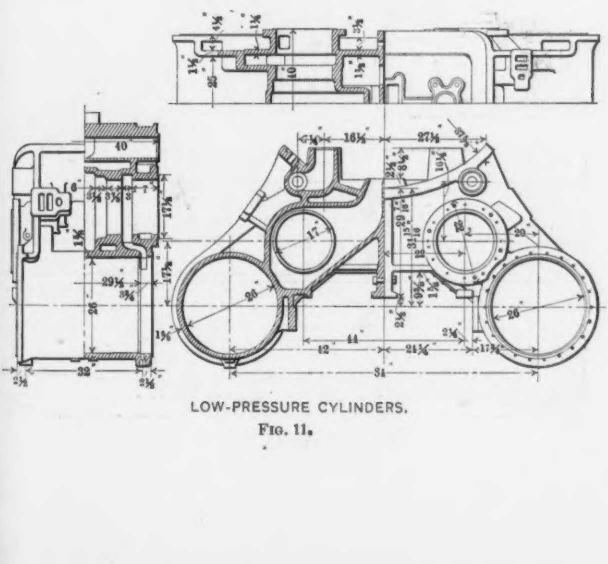


FOUR-CYLINDER BALANCED COMPOUND LOCOMOTIVE NEW YORK CENTRAL RAILWAY.

COLE FOUR-CYLINDER COMPOUND LOCOMOTIVE.



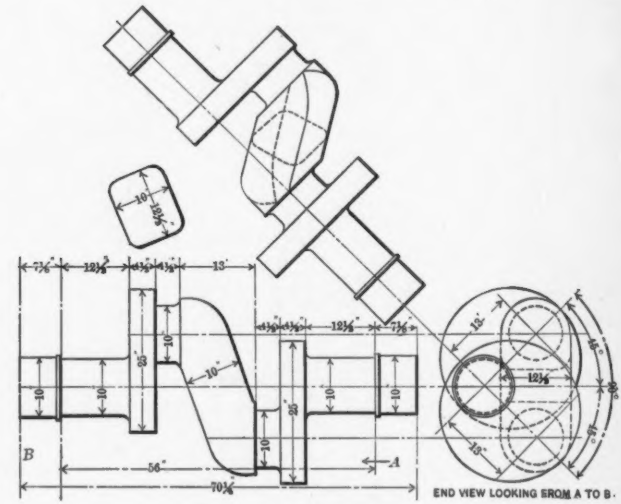
HIGH-PRESSURE CYLINDERS.



LOW-PRESSURE CYLINDERS.

FIG. 11.

COLE FOUR-CYLINDER COMPOUND LOCOMOTIVE.



CRANK AXLE.

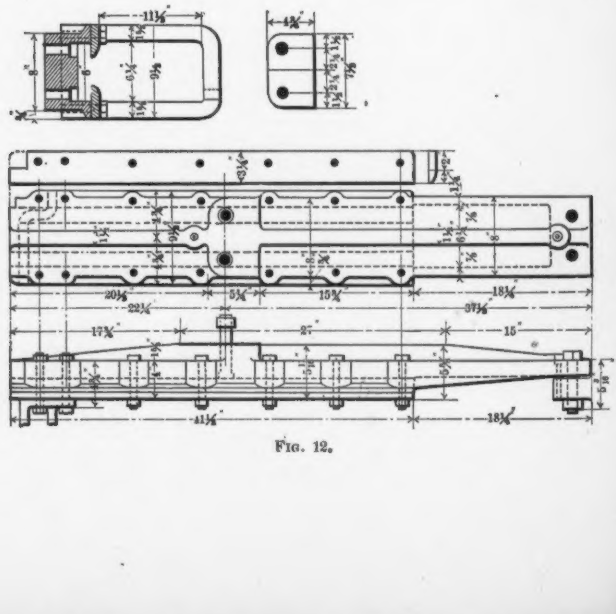


FIG. 12.

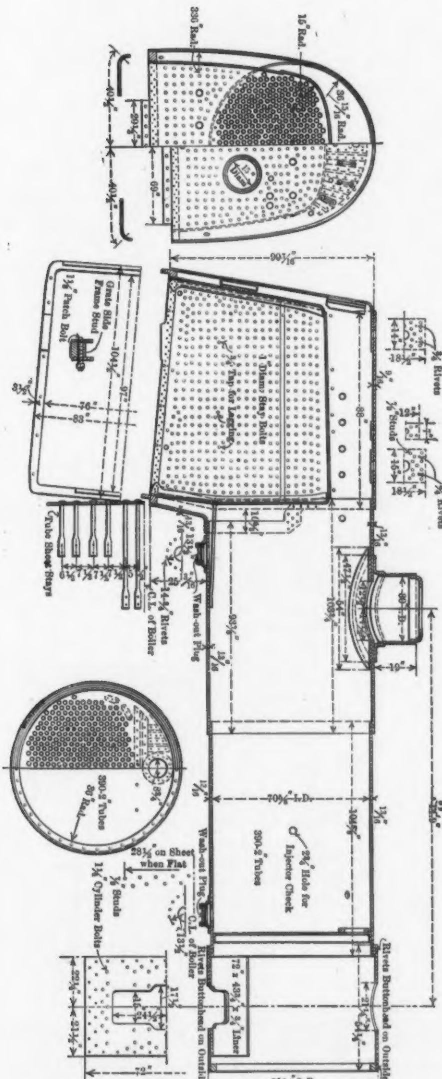


FIG. 13.

BOILER FOR COLE FOUR-CYLINDER BALANCED COMPOUND LOCOMOTIVE.

DIAGRAM OF VALVES AND CYLINDERS OF COLE'S FOUR-CYLINDER BALANCED COMPOUND LOCOMOTIVE.

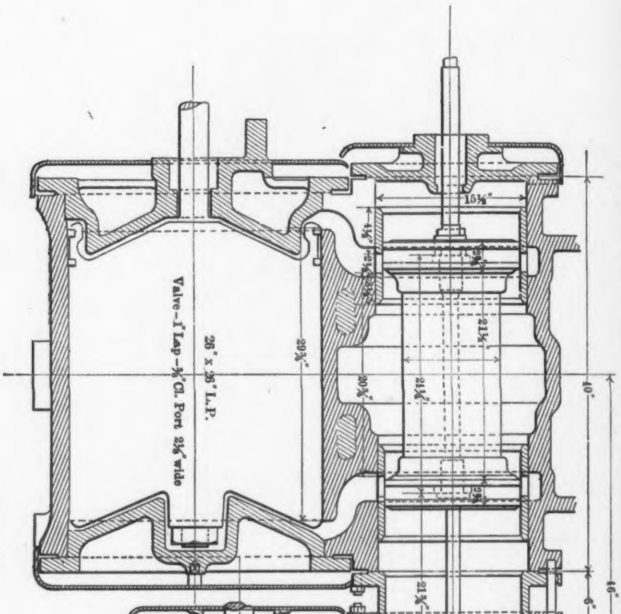
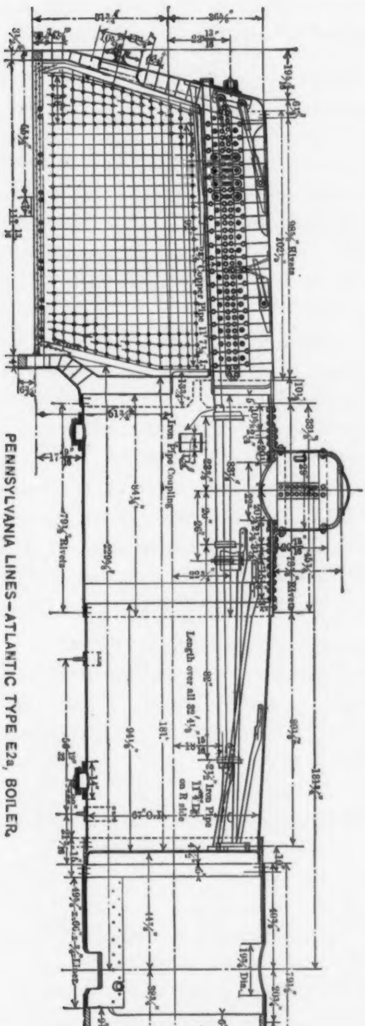


FIG. 14.



PENNSYLVANIA LINES—ATLANTIC TYPE E2a, BOILER.

FIG. 15.

to its outline the semblance of a very large machine. In this engine the principal dimensions are as follows:

Cylinders	20 by 32 in.;
Diameter of drivers...........	55 in.;
Total weight..................	208 000 lb.;
Weight on drivers............	186 000 lb.;
Diameter of boiler............	78 in.;
Boiler pressure...............	200 lb.;
Grate surface.................	82 sq. ft.;
Total heating surface.........	3 172 sq. ft.

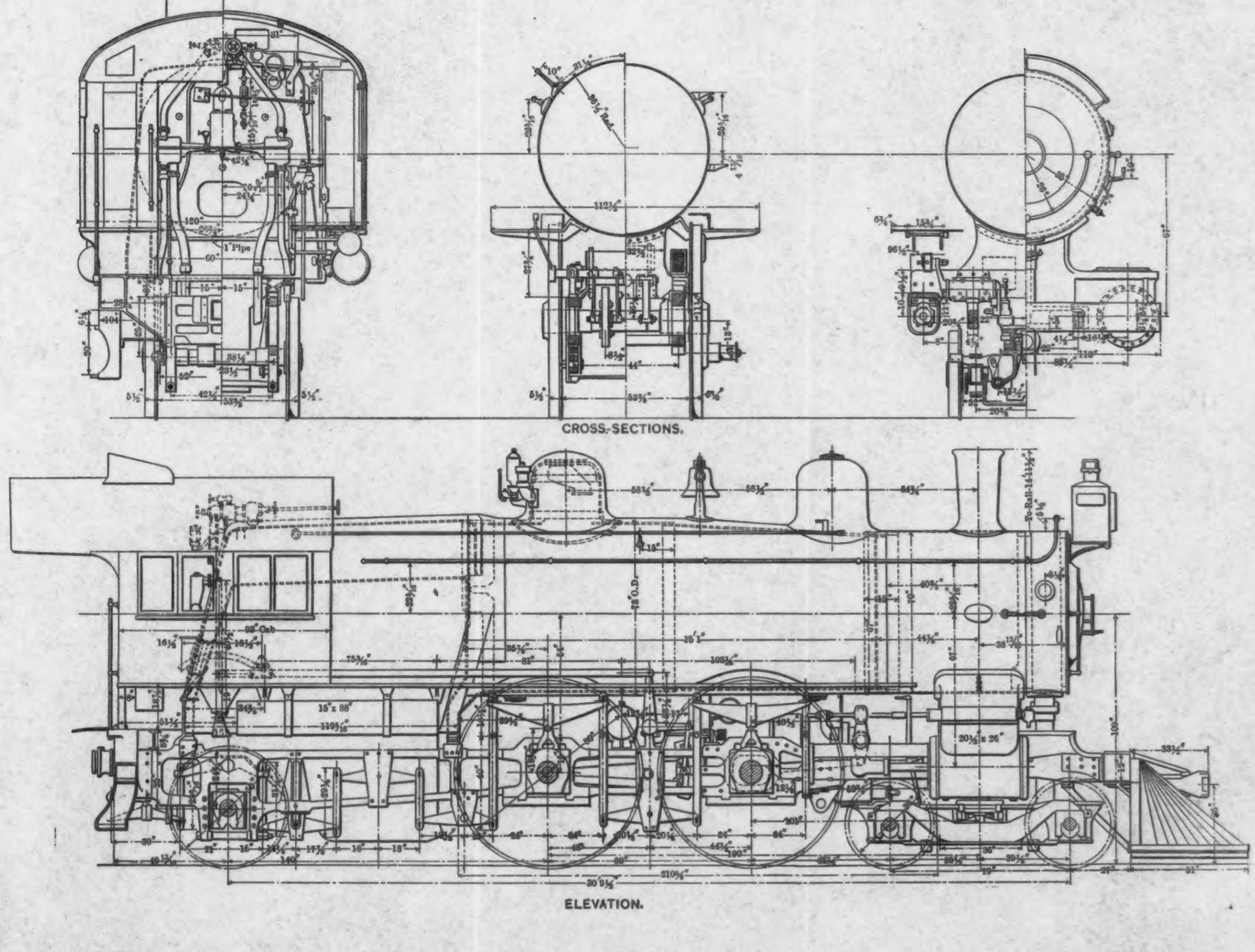
A number of consolidation engines have been built with tandem compound cylinders, and, where greater weight and power have been required, tandem cylinders have been used with the locomotives having five pairs of drivers with pony-truck wheels at the front and back. The locomotives of this type are known as the Santa Fe tandem compound, having been built by the Baldwin Locomotive Works for the Santa Fe Railway. These engines are unusually large and powerful, having a tractive power of 69 500 lb. in starting, and 62 800 lb. when running compound. The tandem cylinders are 19 by 32 in. in diameter and have a 32-in. stroke.

Diameter of drivers...........	57 in.;
Total weight..................	287 240 lb.;
Weight on drivers............	234 580 lb.;
Diameter of boiler............	78¾ in.;
Boiler pressure...............	225 lb.;
Grate surface.................	58.5 sq. ft.;
Total heating surface.........	4 796 sq. ft.

These engines are intended for heavy mountain service, where the grades are 2 and 3 per cent. Seventy of these large engines have been built by the Baldwin Locomotive Works for the Santa Fe Railway. The total weight of the engine and tender, ready for service, reaches the enormous figure of 450 000 lb.

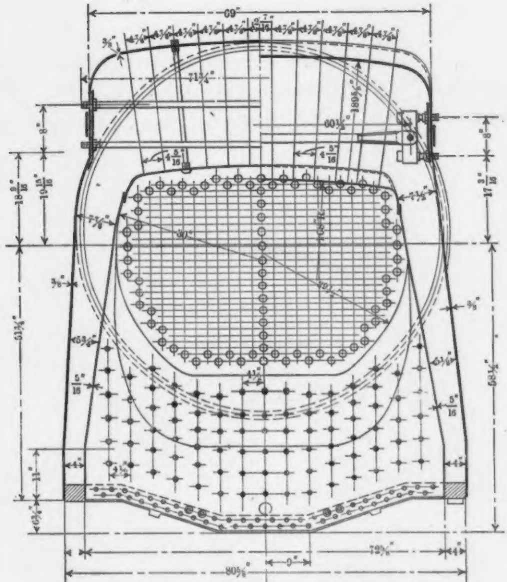
A still larger locomotive, for pushing on heavy grades, has been built recently by the American Locomotive Company, at their Schenectady Works, for the Baltimore and Ohio Railway. This

PENNSYLVANIA LINES—ATLANTIC LOCOMOTIVE, CLASS E2a.



CROSS-SECTIONS.

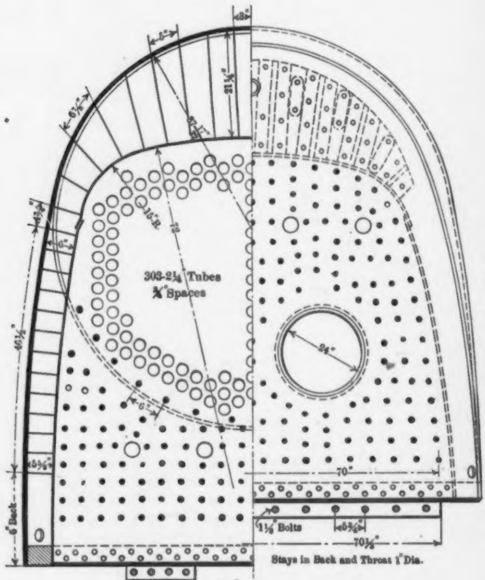
ELEVATION.



PENNSYLVANIA LINES-ATLANTIC TYPE E2a,
CROSS-SECTION OF FIREBOX.
FIG. 16.

PENNSYLVANIA LINES—PISTON VALVE—E2a.
FIG. 17.

locomotive may be considered as consisting of two six-wheel connected locomotives, with their frames coupled, each served by a single boiler fastened rigidly to the frame of the rear engine and allowed lateral swing over the forward six drivers, which act as a separate truck. The high-pressure cylinders are placed longitudinally about the center of the boiler, and they are connected to the



PACIFIC TYPE. NEW YORK CENTRAL RAILROAD.
FIG. 18.

rear set of drivers. The steam pipe passes down on the outside of the boiler directly from the dome to the cylinders, and the exhaust from the high-pressure cylinders passes through a pipe, located between the frames, to the low-pressure cylinders, which are in front. As the latter cylinders are placed some distance ahead of the stack,

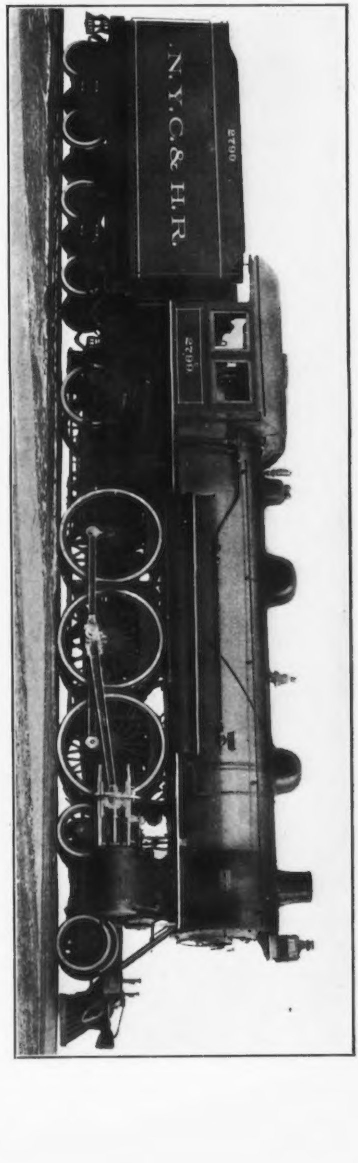


FIG. 1.—PACIFIC TYPE, NEW YORK CENTRAL AND HUDSON RIVER RAILROAD.

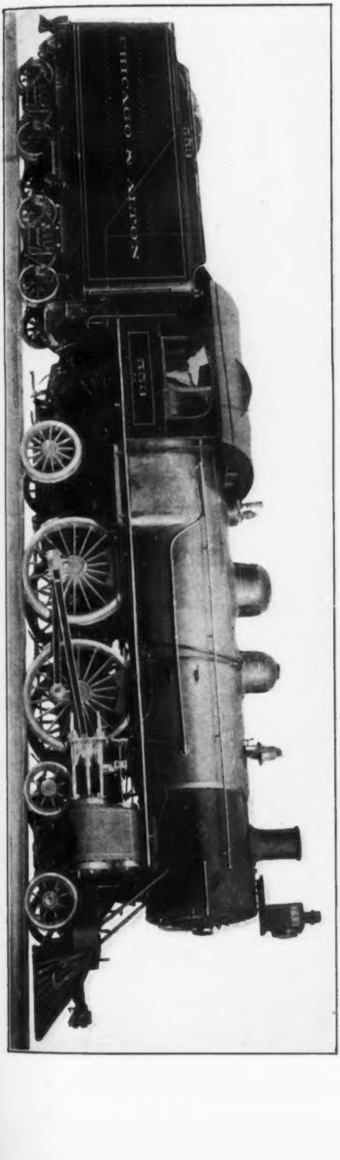


FIG. 2.—ATLANTIC LOCOMOTIVE, CHICAGO AND ALTON RAILWAY.

TRAILING TRUCK AND JOURNAL BOX FOR PACIFIC TYPE. NEW YORK CENTRAL RAILROAD.

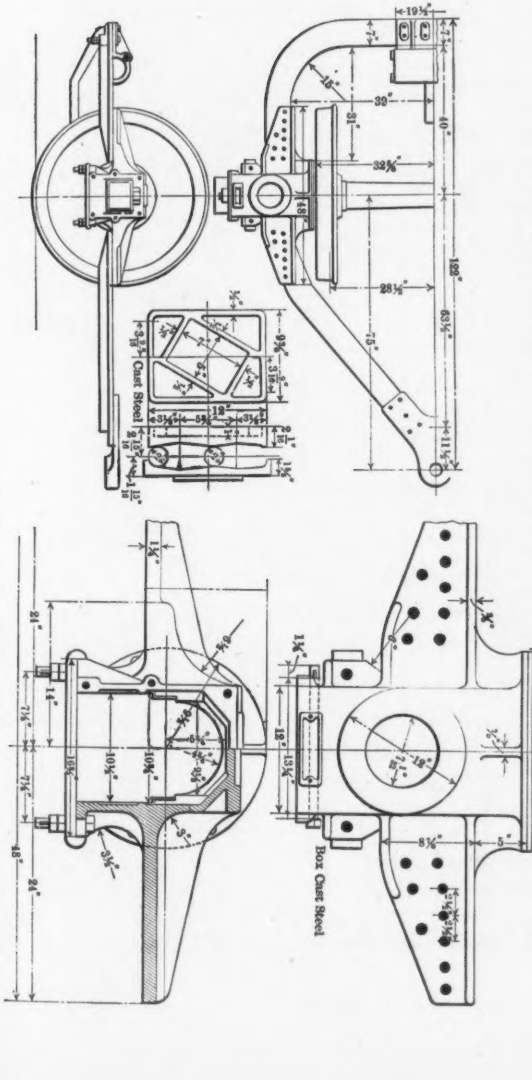


FIG. 19.

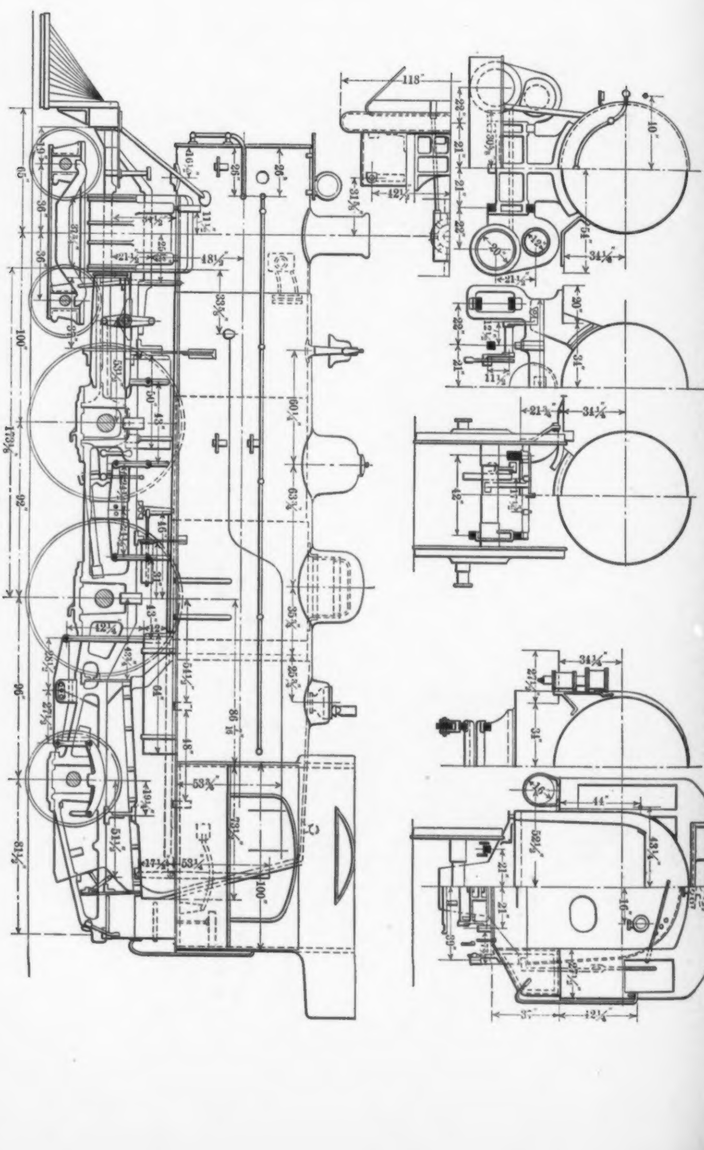


FIG. 20.

CHICAGO AND ALTON ATLANTIC LOCOMOTIVE-ELEVATION AND CROSS-SECTIONS.

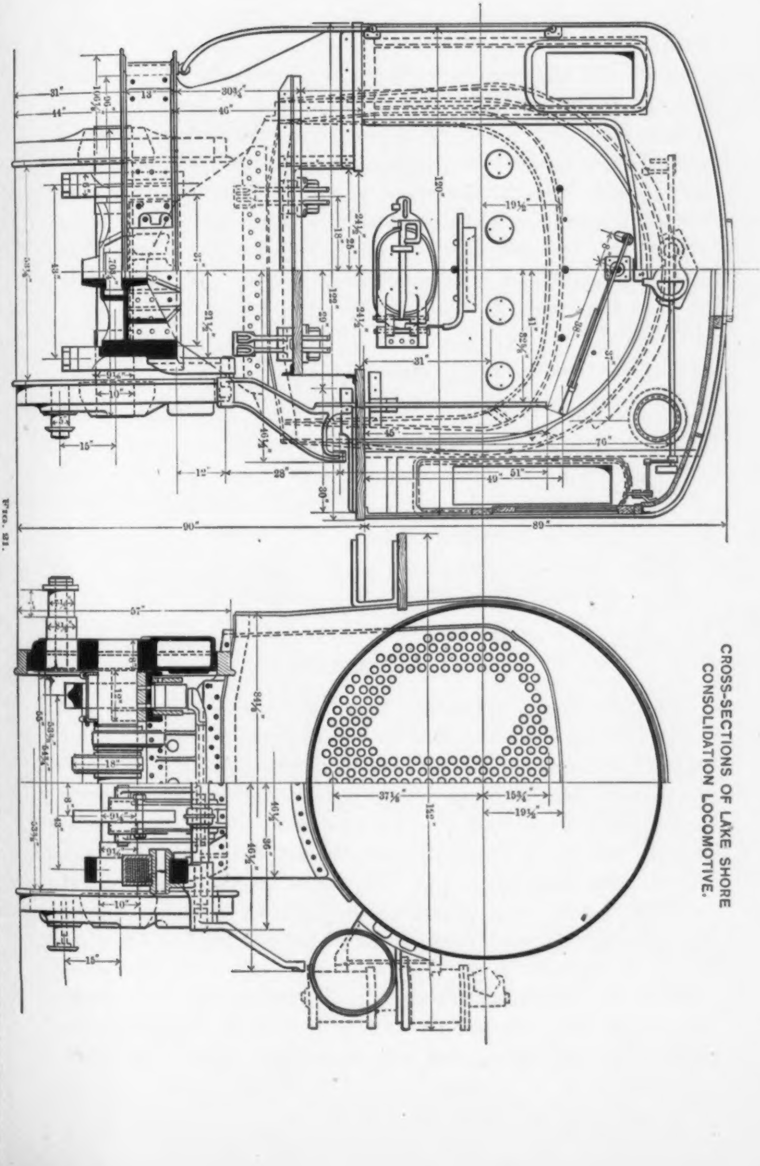


FIG. 21.

CROSS-SECTIONS OF LAKE SHORE CONSOLIDATION LOCOMOTIVE.

it is necessary to use a curved exhaust pipe, and the arrangement of this pipe and of the receiver pipe, in order to provide flexibility, constituted one of the novel problems in connection with the design. The high-pressure cylinders are fitted with piston valves and the low-pressure cylinders with flat slide valves. The Walschaert valve gear is used for both engines, and, on account of the limited space between the frames, it is well adapted to the requirements. This is by far the largest locomotive ever constructed, and the boiler, especially, is of enormous proportions. The engines, being divided into two complete sets, are of ordinary proportions. The maximum tractive effort is 85 000 lb. in starting and 70 000 lb. in working compound. The following are the principal dimensions:

Diameter of cylinders.......	high-pressure, 20 in.; low-pressure, 22 in.;
Stroke	32 in.;
Diameter of drivers..........	56 in.;
Total weight.................	334 500 lb.;
Weight on drivers............	334 500 lb.;
Boiler pressure..............	235 lb.;
Grate surface................	72 sq. ft.;
Total heating surface........	5 585 sq. ft.

Boilers.

The changes in locomotive design, in order to obtain greater power, it will be observed, have been largely due to the use of a larger boiler. The barrel was not only greatly increased in diameter to accommodate a larger number of tubes, but its length was made greater, so that tubes 20 ft. long are frequently used. In 1893 the outside sheet of the firebox in most locomotives was flush with the frame, and the width inside was 42 in. The larger express engines on fast schedules burned such a large quantity of coal per hour that the rate of combustion was often forced to 150 and 200 lb. of coal per sq. ft. of grate per hour. The same was true of freight engines when hauling maximum trains, even at comparatively slow speeds. The strong blast required for such high rates of combustion was sufficient to pull unconsumed fuel through the tubes to the extent

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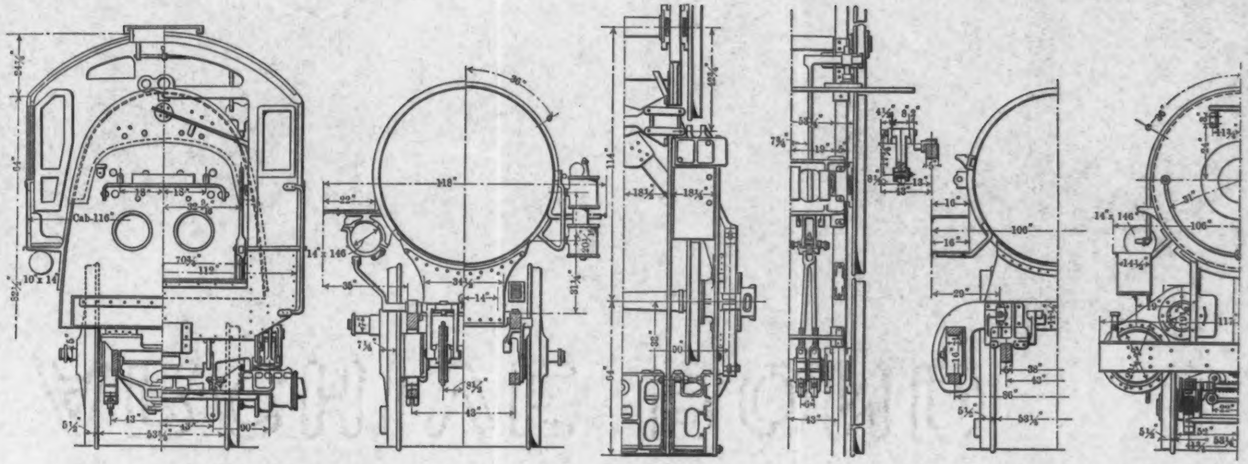
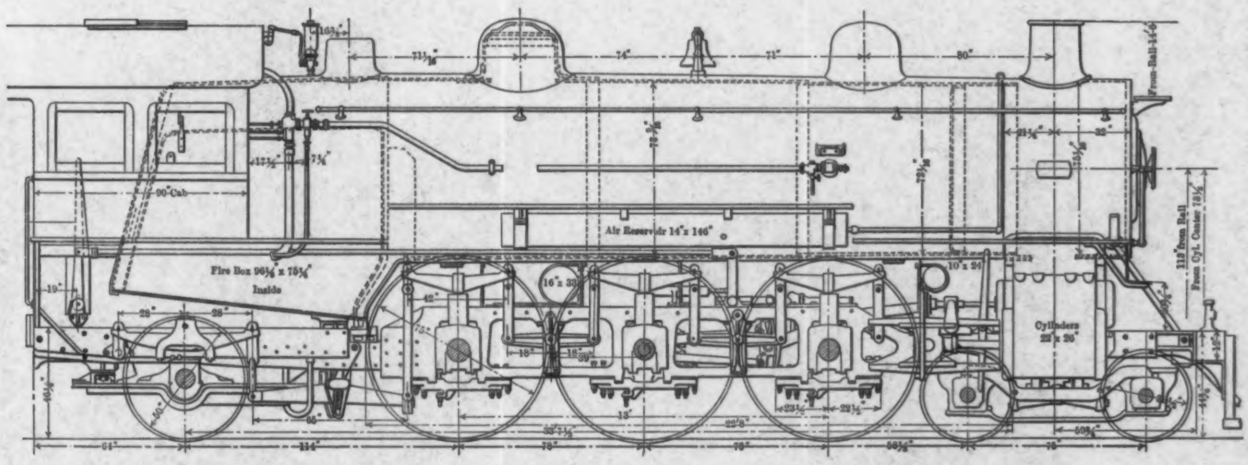
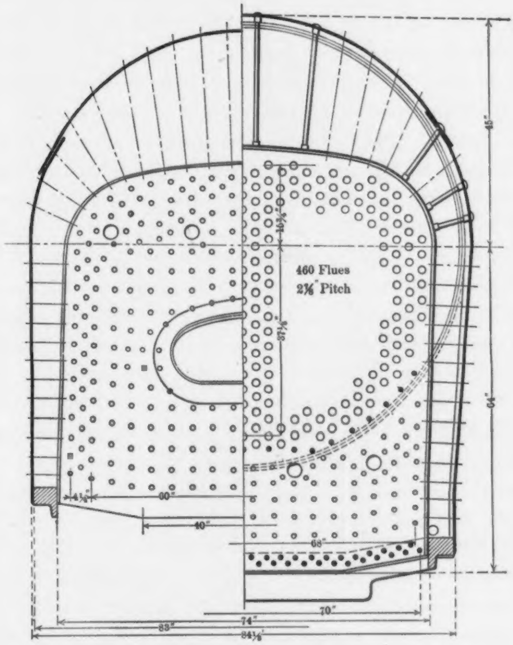
AMERICAN LOCOMOTIVES.



PACIFIC TYPE. NEW YORK CENTRAL RAILROAD.



of 10 or 15% of the total coal fired, and throw it out of the stack, and the rate of evaporation was thus reduced. Even with such high rates of combustion, it was not possible to burn sufficient coal on a grate 42 in. wide to supply large engines with steam. A fast passenger engine, with cylinders 19 by 24 in., burned three tons of coal per hour, and since that time passenger engines with 45% greater cyl-



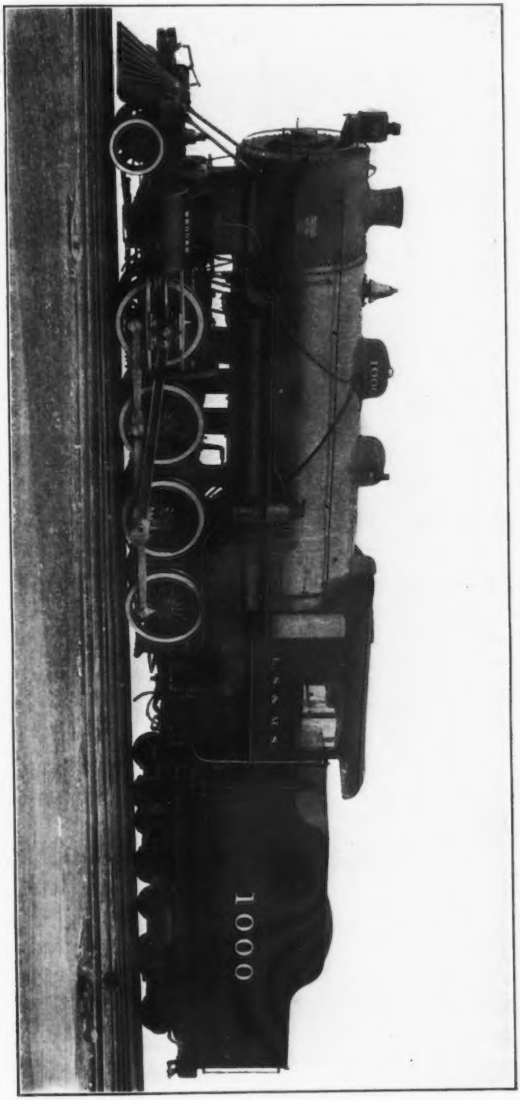
CROSS-SECTION OF FIRE BOX, LAKE SHORE CONSOLIDATION LOCOMOTIVE
FIG. 22.

inder volume have been built. It was found necessary to increase the width of the firebox to 5, 6 and 7 ft., and such boxes are known as "medium-wide" fireboxes, to distinguish them from those 8 ft. wide, used on anthracite boilers. The wide firebox was easily applied to types of passenger engines having trailing wheels, such as the Columbia, Atlantic and Pacific, and in the consolidation type the

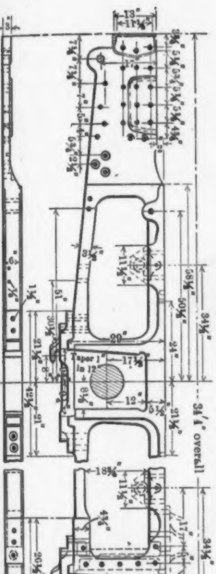
diameter of drivers is so small that the wide box could be easily extended over the rear pair of that type. In placing the firebox entirely back of the drivers on passenger engines, the throat sheet has been inclined forward, so that the front water leg conforms somewhat to a line parallel with the circumference of the rear driver, and the tube sheet is thus somewhat ahead of the water leg in that region. This is done for the purpose of retaining a proper proportion of weight on the drivers, to avoid tubes of too great length, and to improve the circulation of water along the lower side sheets. The front tube sheet is often placed some distance back of the cylinder saddle for the purpose of avoiding excessive tube length.

The Spacing of Tubes.—The development of the locomotive in America has been based upon a desire for increased tractive power, this power being the maximum to be obtained when using steam at nearly full stroke, and a mean pressure equal to 85% of the boiler pressure. With an average coefficient of adhesion of 25%, the weight on the drivers is determined, and, in order to obtain it, a large boiler diameter was found necessary. Having a large shell, it was thought desirable to fill it as full of tubes as possible, with bridges of only $\frac{5}{8}$ in. between the tubes, and when the tubes are coated with scale the space is reduced to $\frac{3}{8}$ in. at least. At the same time, the height of the evaporating surface above the lower tubes was greatly increased, and, with it, the length of travel of steam bubbles. Under such conditions, the tubes are not constantly covered with water, and they become overheated, resulting in leaks at the tube sheets. This has been one of the most serious troubles in the operation of large locomotives, and in locomotives built in 1904 there is a marked tendency to use a less number of tubes in a shell of the same size, and to increase the space between tubes from $\frac{5}{8}$ to $\frac{3}{4}$ or $\frac{7}{8}$ in.

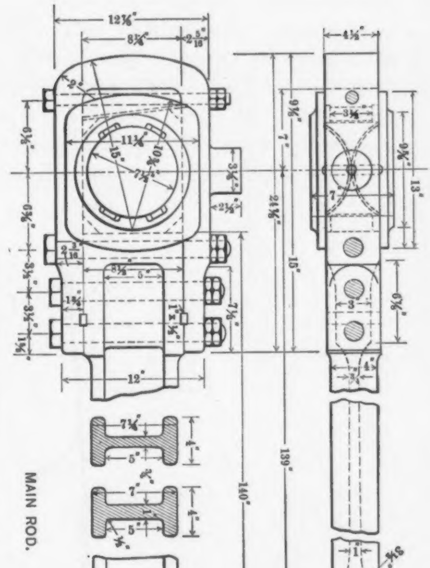
It was found that the maximum efficiency of the tube-heating surface could not be obtained by such close spacing, and it is believed that a higher rate of evaporation per square foot of heating surface will be obtained when the tubes are spaced further apart, and that, therefore, an equivalent or larger boiler capacity will be obtained with a less number of tubes with the wider spacing. An illustration of this is found in two lots of Pacific type passenger engines, built by the same works for the same road, those in 1903



SIMPLE CONSOLIDATION LOCOMOTIVE, LAKE SHORE AND MICHIGAN SOUTHERN RAILROAD.



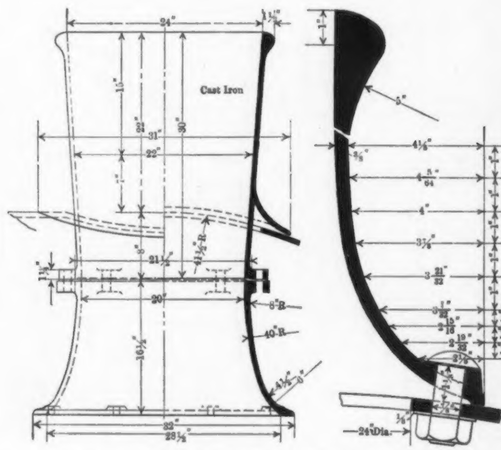
MAIN FRAME—BACK AND FRONT PEDESTALS.
Fig. 23.



MAIN ROD.

LAKE SHORE CONSOLIDATION LOCOMOTIVE.

having the close tube spaces and those in 1904 the wider spaces. The diameter of the boiler is the same, and the tubes are 20 ft. long in each case. Those built in 1903 had 328 tubes and those in 1904 245 tubes, a difference of 83. The total heating surface is reduced from 4 078 to 3 053 sq. ft., a difference of 1 025 sq. ft., or 25 per cent. The width of the mud ring and water space at the bottom is increased to 5 in. With such proportions for the water space between the tubes and in the water leg, the circulation of the water is



STACK, LAKE SHORE CONSOLIDATION LOCOMOTIVE.
FIG. 24.

greatly improved and the efficiency of the heating surface is increased.

LOCOMOTIVE OPERATION, AS AFFECTED BY THE FIREMAN.

In the operation of large locomotives with wide fireboxes it is found that the fuel economy, the hauling capacity and the boiler repairs (especially firebox sheets and tubes) are all materially affected by the limitations of the strength of the fireman, and by his lack of skill in keeping the grate covered uniformly with coal.

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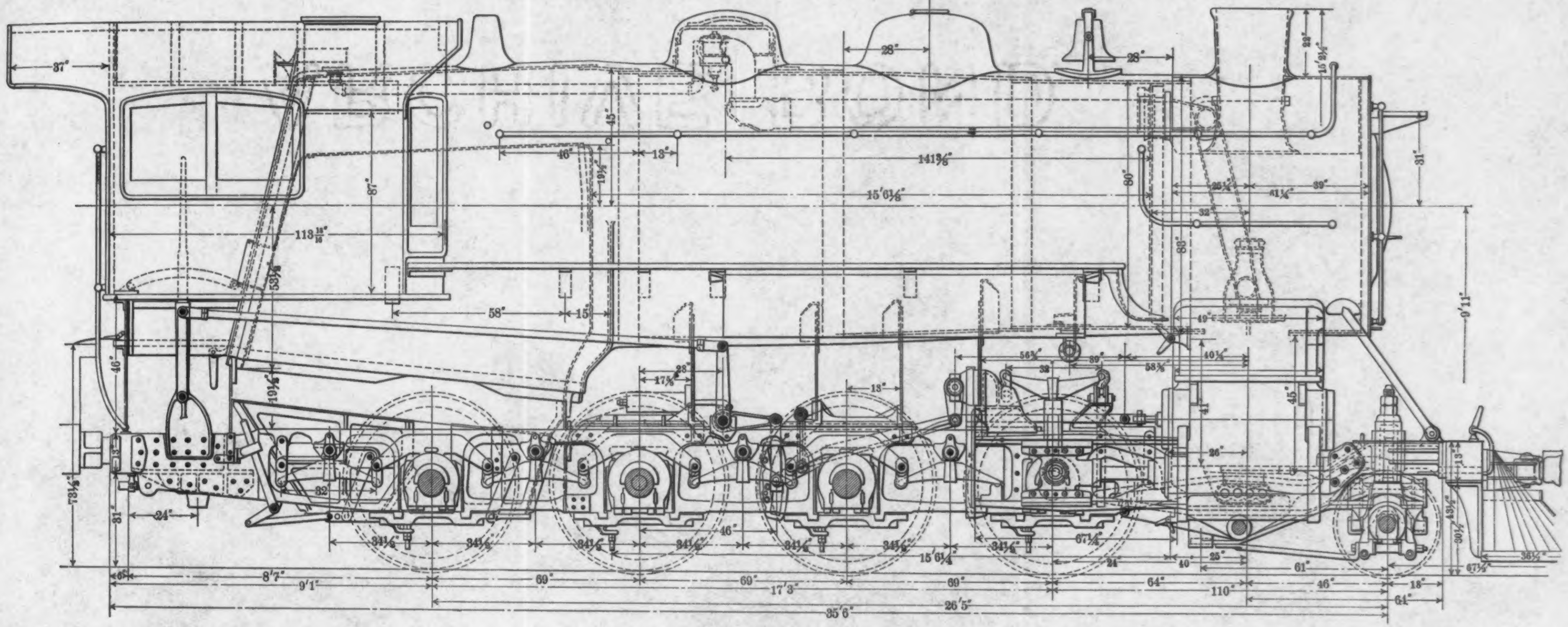
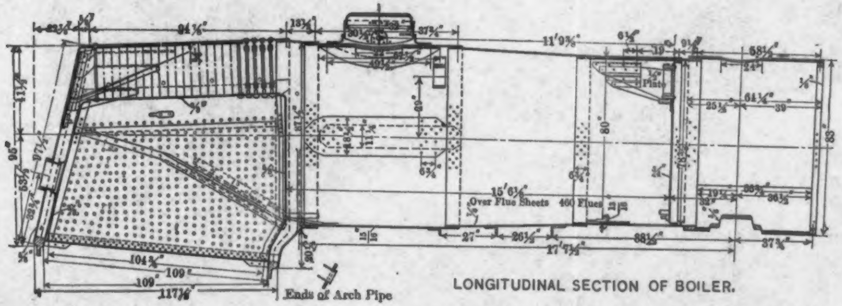
LAKE SHORE AND MICHIGAN SOUTHERN RAILWAY CONSOLIDATION LOCOMOTIVE.





LONGITUDINAL SECTION OF BOILER.

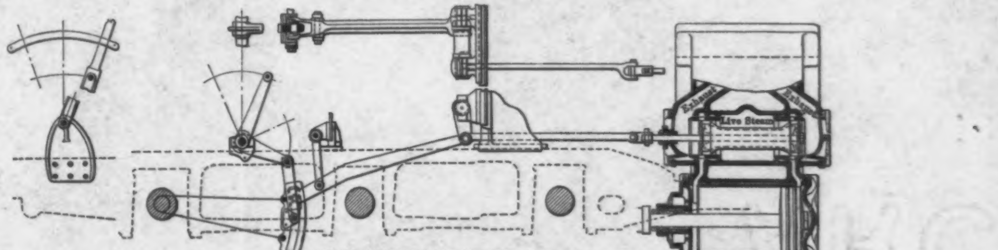
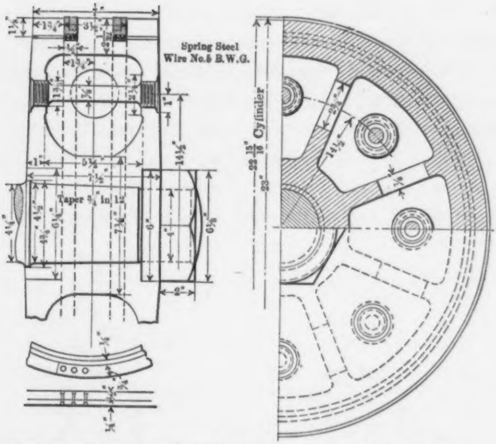
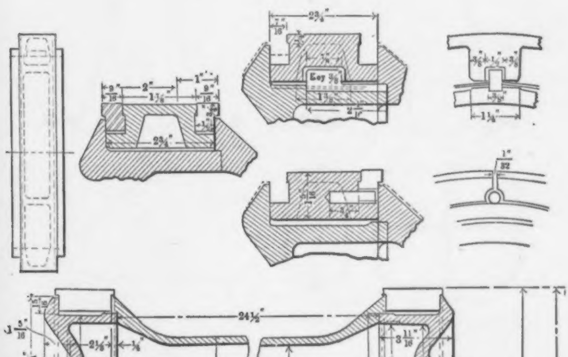


DIAGRAM OF LINK MOTION AND CYLINDER.



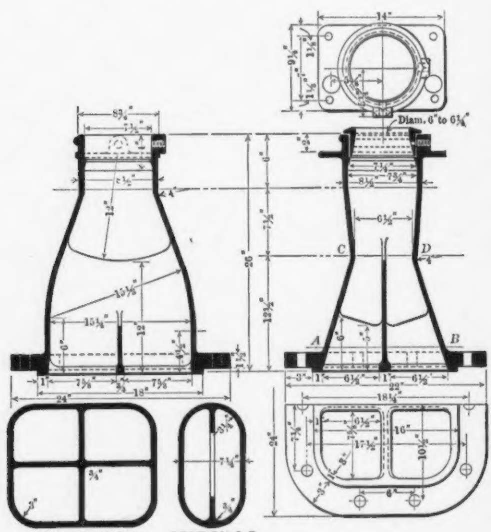
PISTON HEAD, LAKE SHORE CONSOLIDATION LOCOMOTIVE.
FIG. 25.



PISTON VALVES, LAKE SHORE CONSOLIDATION LOCOMOTIVE
FIG. 26.

From the facts contained in recent reports to the Master Mechanics' Association, the following conclusions may be drawn:

First, that in recent years poor material has often been employed for firemen. Second, that poor firemen are most extravagant in coal consumption when working wide fireboxes. Third, that the irregular firing of wide fireboxes has resulted in leaky tubes and cracked sheets. Fourth, that the capacity of a large locomotive is easily limited by the endurance of the fireman, whether good



SECTION A-B SECTION C-D

EXHAUST NOZZLE, LAKE SHORE CONSOLIDATION LOCOMOTIVE.

FIG. 27.

or bad. Fifth, that the economic size of locomotives may in some instances have been exceeded on account of the limitations of the fireman's strength.

The care with which wide fireboxes should be fired is not generally appreciated by the men, and is largely the cause of the numerous troubles due to leaking, which are experienced with this type of boiler. It is more difficult to maintain an even fire on a large grate than on a small one, and as there is a greater tendency to

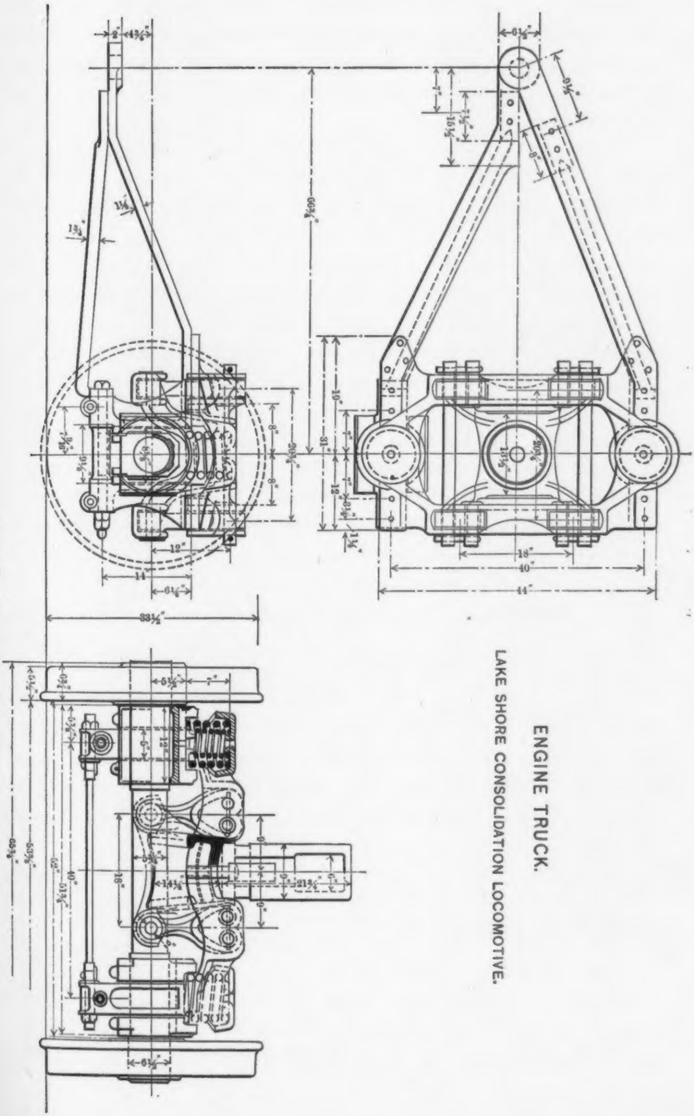


FIG. 28.

ENGINE TRUCK.

LAKE SHORE CONSOLIDATION LOCOMOTIVE.

irregular temperature in the former, it is the direct cause of leakage. The admission of larger amounts of cold air to the furnace than is necessary for combustion has a tendency to lower the average temperature of the firebox gases, and thus to reduce the rate of evaporation.

It is, for this reason, easily possible for the fireman to affect unfavorably the coal performance with wide fireboxes, even when he is endeavoring to do his best work. The rules relating to the privileges due to priority of service of firemen have had a tendency to place the youngest and most unskilled men on the large engines with wide fireboxes, because the older men prefer the lighter work on the smaller locomotives. Although the rate of wages paid firemen is higher than that received by skilled mechanics, who have spent several years in learning a trade, or of clerks, who are perhaps better educated, yet the fireman's service is no longer attractive to a good grade of men, on account of the laborious work required in handling the large amount of coal consumed per trip by large locomotives.

It has been shown in the reports referred to that, as now operated, the wide firebox is not superior to the narrow one in economy of fuel, and coal consumption must be nearly proportional to the horse-power developed with either type of boiler. As the large locomotives have a horse-power capacity nearly double that of the medium-sized engines used a few years ago, the amount of coal to be handled per hour when these engines are working at normal capacity must be twice as great. While the fireman may be able to handle this amount of coal for the first few hours, he cannot keep up the work uniformly for the whole trip. The Master Mechanics' report on automatic stokers emphasized this fact in explaining the conditions under which the machine stoker will prove most valuable:

"When the engine is loaded to maximum capacity the automatic stoker will not tire, and consequently it will enable the engine to carry maximum pressure all of the time and get the full benefit of the tractive power of the engine over a long, continuous trip; this cannot be done by hand-firing."

The power of the large locomotive is thus limited by the fireman in his failure to maintain uniformly full boiler pressure, due to the limitations of his physical endurance. So far as irregular

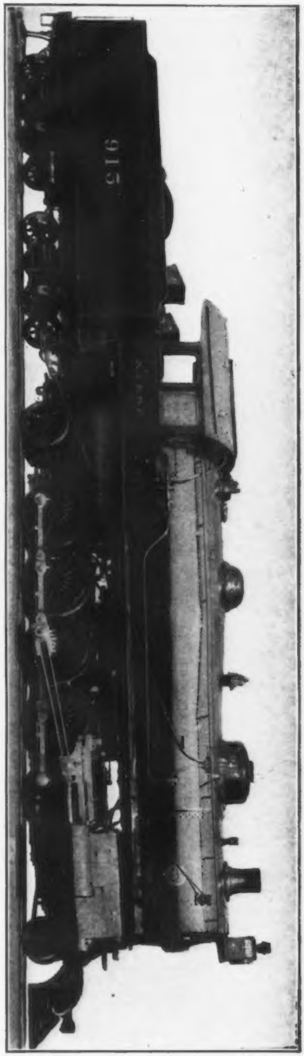


FIG. 1.—SANTA FÉ 2-10-2 TYPE. TANDEM COMPOUND.

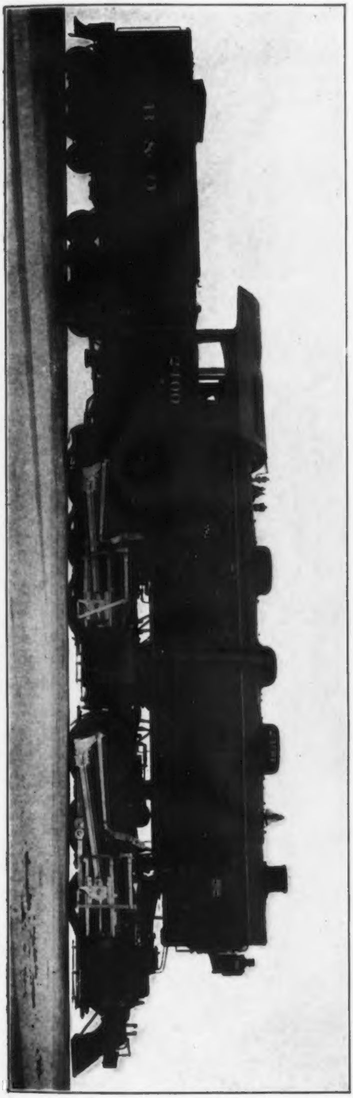


FIG. 2.—MALLET ARTICULATED COMPOUND LOCOMOTIVE.

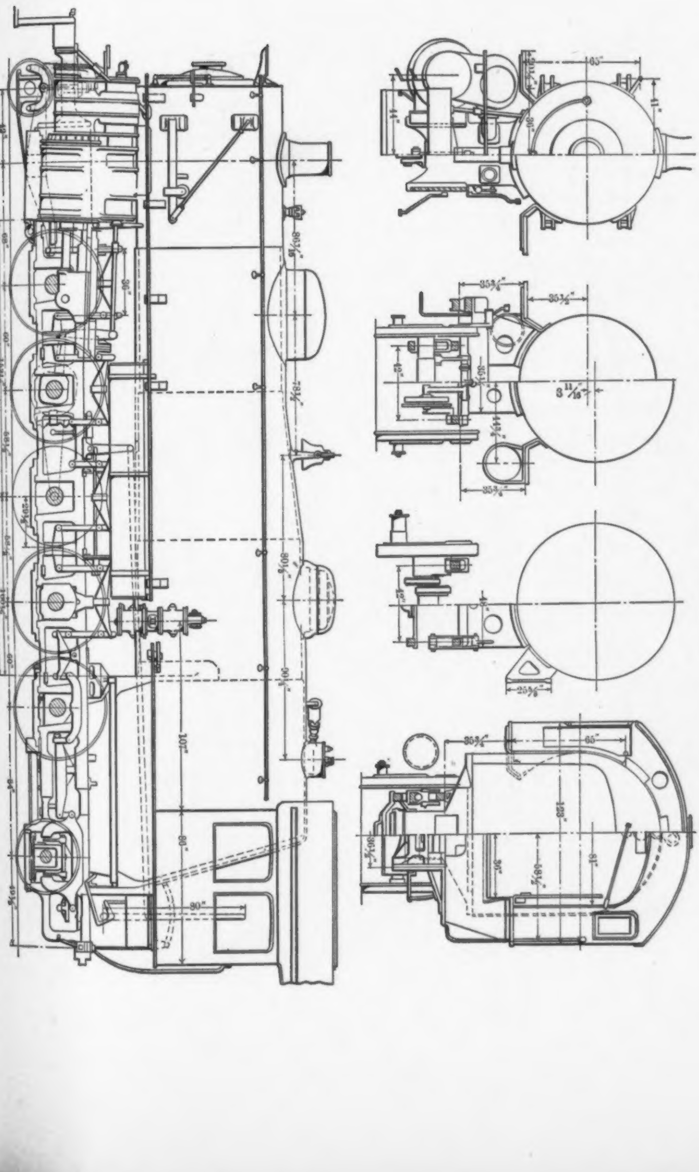
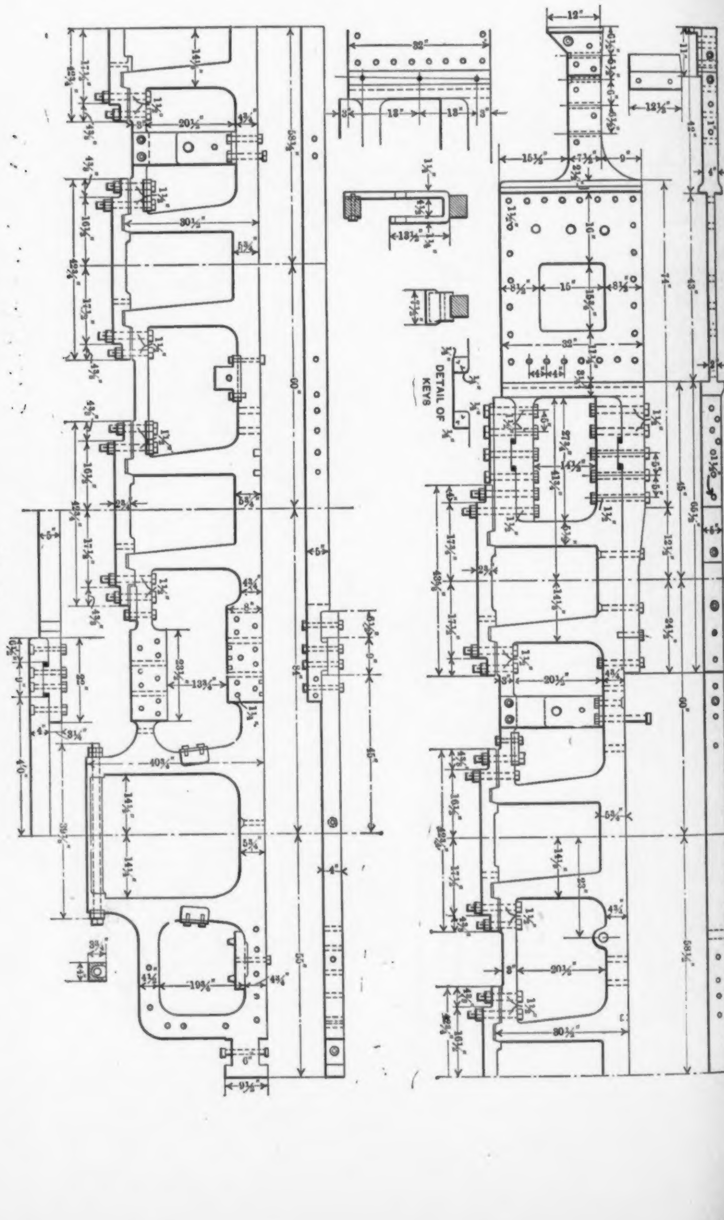


FIG. 20.

SANTA FE TANDEM COMPOUND—LONGITUDINAL AND CROSS-SECTIONS.



SANTA FE TANDEM COMPOUND—MAIN FRAMES.

FIG. 30.

SANTA FE TANDEM COMPOUND—SECTIONS OF BOILER.

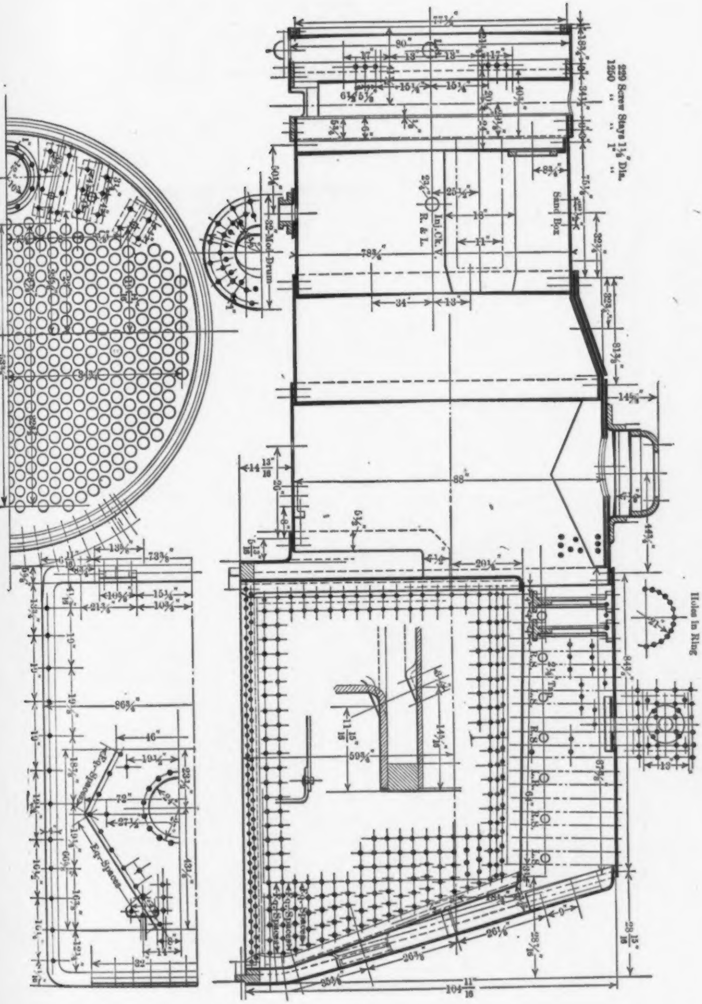
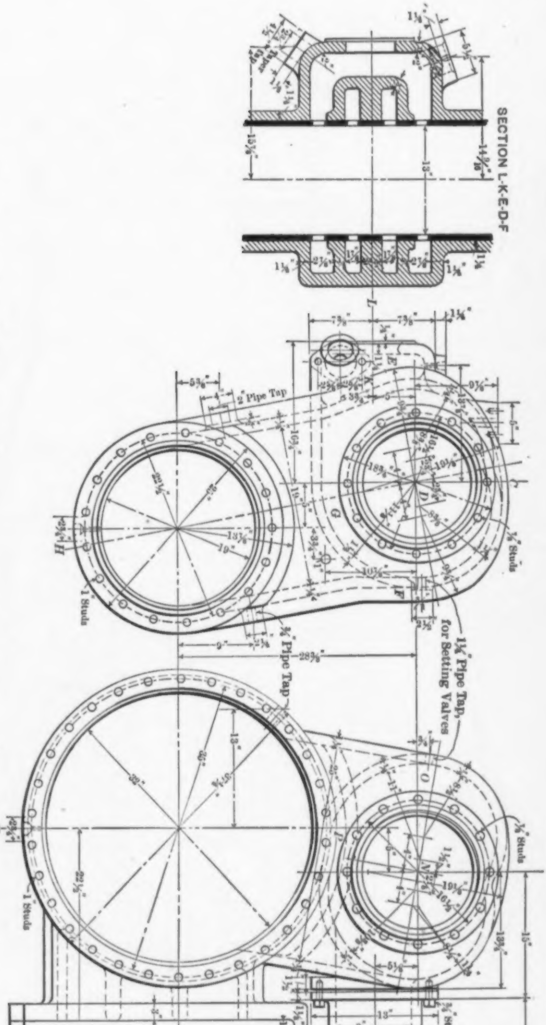
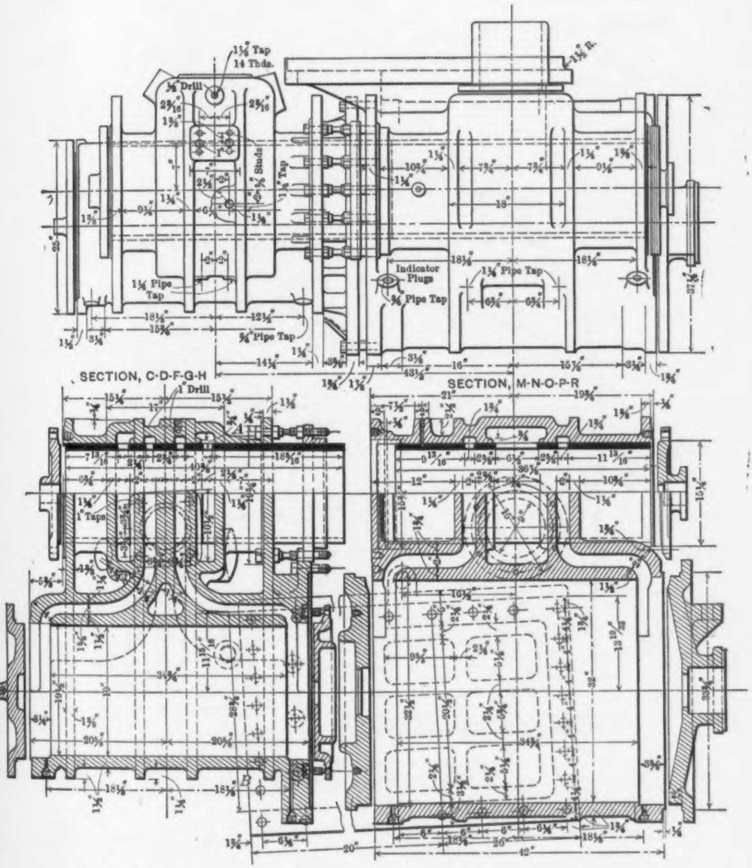


FIG. 31.



SANTA FE TANDEM COMPOUND—END ELEVATIONS OF HIGH-AND LOW-PRESSURE CYLINDERS AND VALVES.

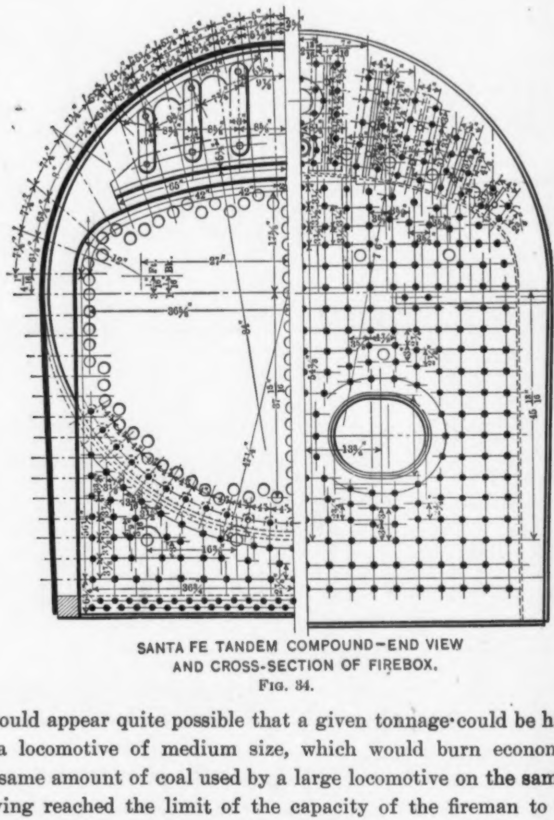
FIG. 32.



SANTA FE TANDEM COMPOUND - PLAN AND LONGITUDINAL SECTION OF CYLINDERS.
FIG. 33.

firing results in failures of the boiler and firebox, to that extent does the fireman determine the mileage service of the engine, for such failures require it to be laid up in round-house or shop, and there is a loss, due not only to cost of repairs, but to the limited service obtained on the road.

If the above statements be considered with relation to the size of locomotives as measured by their coal consumption per hour,



SANTA FE TANDEM COMPOUND—END VIEW AND CROSS-SECTION OF FIREBOX.
FIG. 34.

it would appear quite possible that a given tonnage could be handled by a locomotive of medium size, which would burn economically the same amount of coal used by a large locomotive on the same trip. Having reached the limit of the capacity of the fireman to shovel coal enough to maintain uniform boiler pressure, is it a profitable move to build locomotives still larger, and in some instances has

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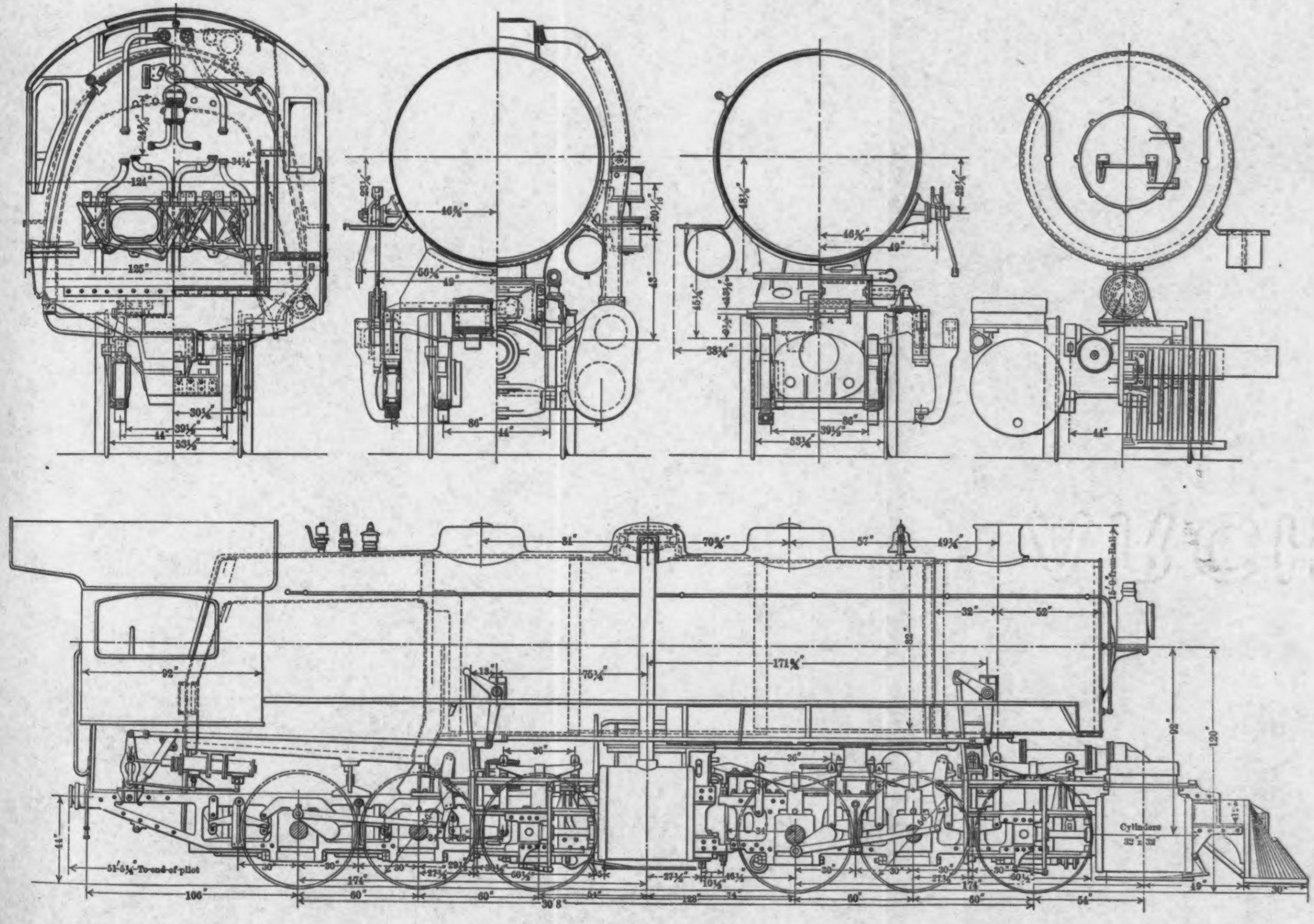
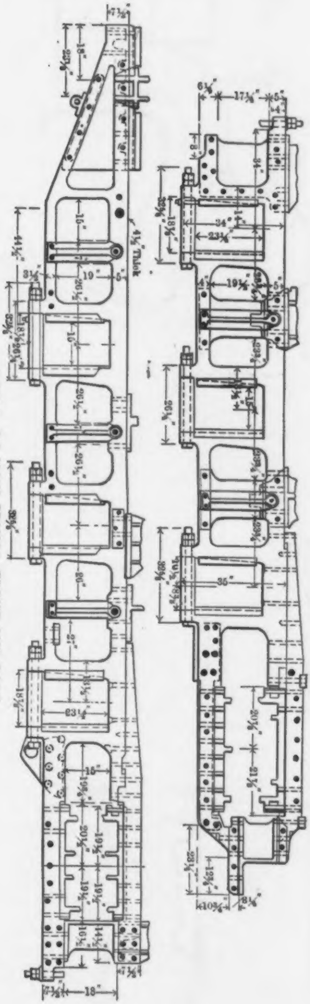
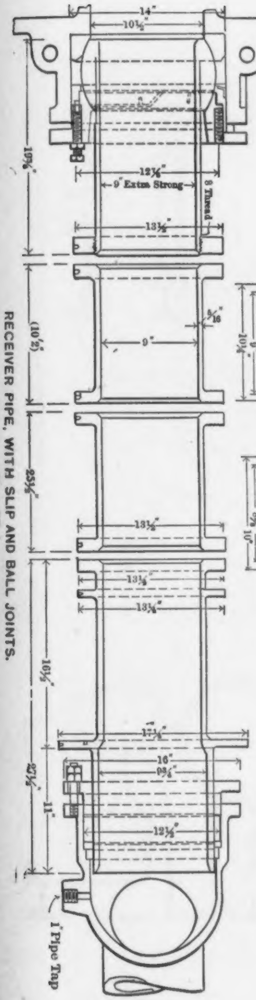
MALLET ARTICULATED LOCOMOTIVE BUILT FOR THE BALTIMORE AND OHIO RAILROAD BY THE AMERICAN LOCOMOTIVE COMPANY.



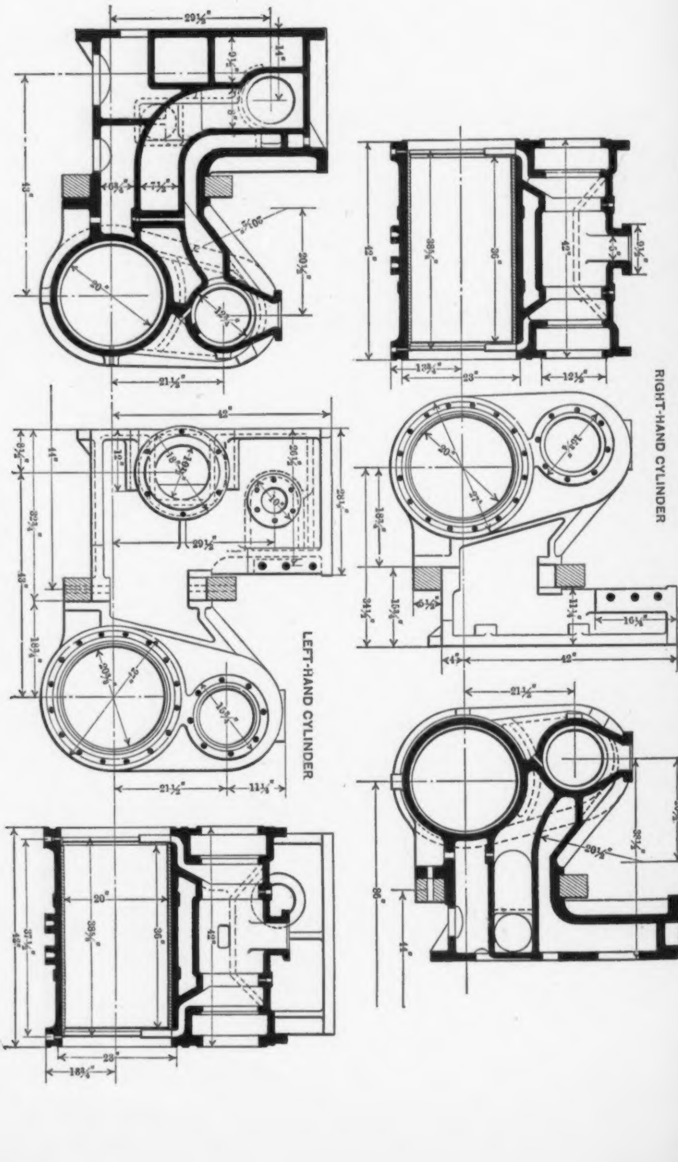
MALLET COMPOUND LOCOMOTIVE.



DETAIL OF MAIN FRAMES, FRONT AND BACK.



RECEIVER PIPE, WITH SLIP AND BALL JOINTS.
FIG. 85.



MALLET COMPOUND LOCOMOTIVE—HIGH-PRESSURE CYLINDER, RIGHT AND LEFT HAND.

FIG. 36.

MALLET COMPOUND LOCOMOTIVE LOW-PRESSURE CYLINDERS
RIGHT AND LEFT HAND.

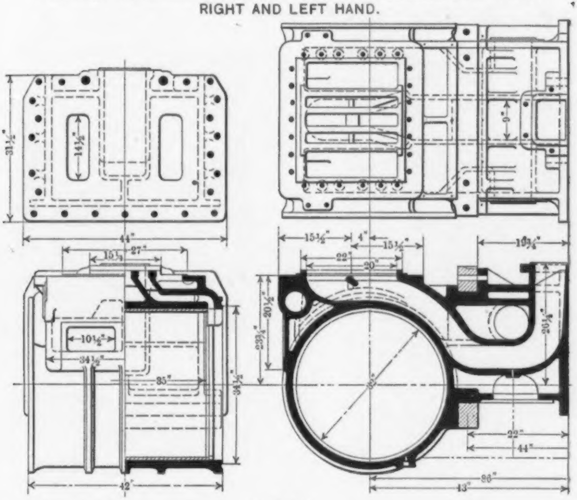
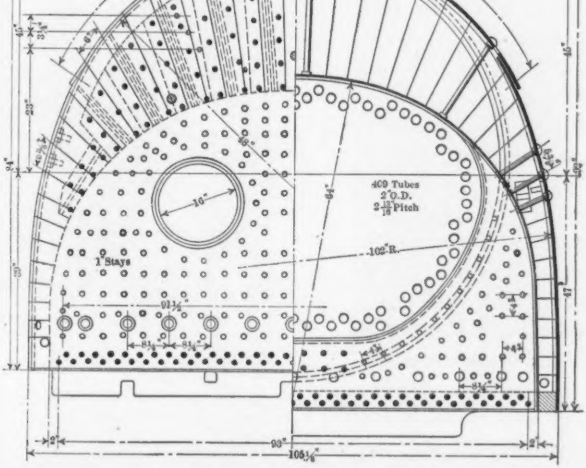


FIG. 37.

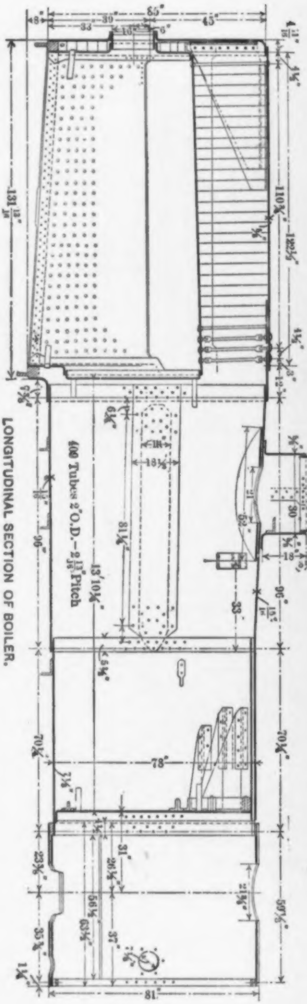


CONSOLIDATION LOCOMOTIVE—CENTRAL RAILROAD OF NEW JERSEY.
END VIEW AND SECTION OF FIREBOX.
FIG. 38.

not the economical size of hand-fired locomotives been more than reached? With oil fuel or with a machine stoker it is possible to force steam production and maintain uniform pressure beyond the maximum of present consumption, and it is only by the use of such measures that the continued growth of the locomotive in America may be justified.

Automatic Stokers for Locomotives.

The necessity for an automatic stoker for the large locomotive, either passenger or freight, is quite generally recognized, and the requirements have been met in a very satisfactory manner by the stoker here described. It is strange, therefore, that a stoker which has been upon the market for several years, and which works so successfully, does not bebecome regularly adopted by the railways, which seem to need some such appliance to assist the fireman in his arduous work. The testimony as to the success of this device is the most convincing of any relating to



CONSOLIDATION LOCOMOTIVE. CENTRAL RAILROAD OF NEW JERSEY.

LONGITUDINAL SECTION OF BOILER.

Fig. 39.

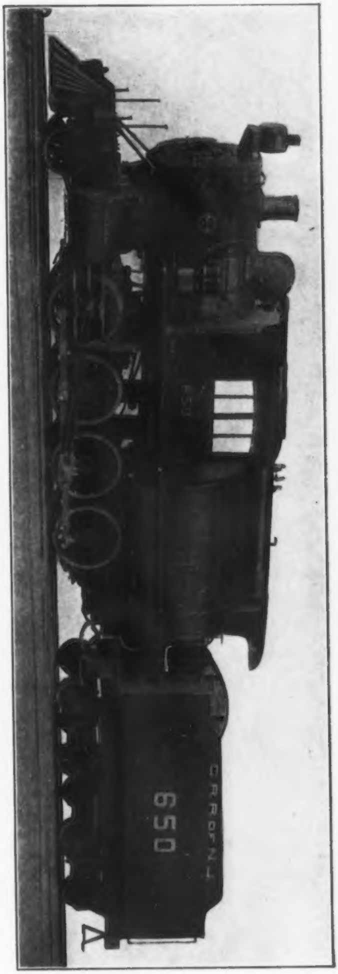


FIG. 1.—CONSOLIDATION LOCOMOTIVE, CENTRAL RAILROAD OF NEW JERSEY.

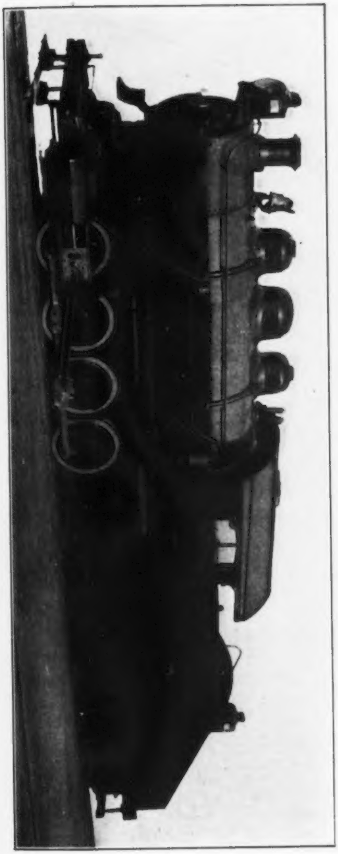
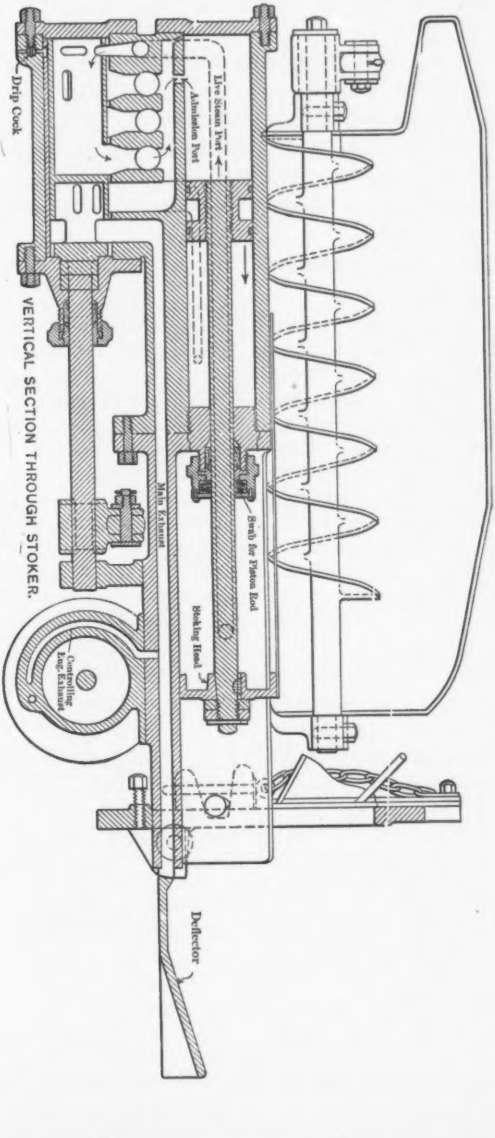


FIG. 2.—EIGHT-WHEEL SWITCHING LOCOMOTIVE, CHESAPEAKE AND OHIO RAILWAY.

CONSOLIDATION LOCOMOTIVE. CENTRAL RAILROAD OF NEW JERSEY.

DAY-KINCAID STOKER FOR LOCOMOTIVES.



VERTICAL SECTION THROUGH STOKER.

FIG. 40.

locomotive improvements (containing such radical changes in methods of operation) which have been introduced in many years. The reports of the laboratory tests at Purdue show it to have given a very satisfactory performance. The testimony of motive power men who have had quite a number of stokers in use is entirely favorable to the device, and the opinion of the superintendent of our largest locomotive works is that the stoker is the coming device. In order to elaborate these facts, the writer may quote from the various authorities referred to.

In regard to the tests of this stoker at Purdue University, Professor Goss says:

"As a smoke consumer, the stoker may be depended upon to give the most satisfactory results. In firing by hand smoke can be suppressed by putting in a shovelful at a time, and the stoker is the refinement of this system. Instead of firing one shovel at a time it fires one-tenth of a shovel, and this tenth is scattered over a third of the area of the grate. The grate is well covered and coal burns uniformly over the whole surface and does not smoke. The action of the stoker, as disclosed by the test, was in every way satisfactory, whether the firing was heavy or light. The device supplies the means by which an engine, however large, may be stoked to its full capacity during long intervals of time with the same ease as used in firing a small engine. As a piece of mechanism its action is satisfactory. The rate of delivery is controllable within wide limits."

Mr John F. Walsh, Superintendent of Motive Power of the Chesapeake and Ohio Railroad, has had a number of the stokers in use for some time. He says:

"It results in a saving of 7% of fuel over the best fireman and double that percentage over an ordinary fireman or stoker. On account of the fact that the fire door is not open when the automatic stoker is used, the cold air does not cause leaky tubes, and an engine fitted with the stoker will run three times as long without making it necessary to hold it in for calking or rolling tubes. The firebox sheets are also protected from a wide variation in temperature due to the inrush of air through the fire door, when the locomotive is fired by hand. The prevention of smoke by the stoker is an assured fact. The class of engine upon which the stoker appears to be most valuable is the heavy type, either passenger or freight, with long firebox. The stoker, being a mechanical device, does not tire, and it continues to keep the grate surface covered from one end of the run to the other, while with hand-fired engines of the

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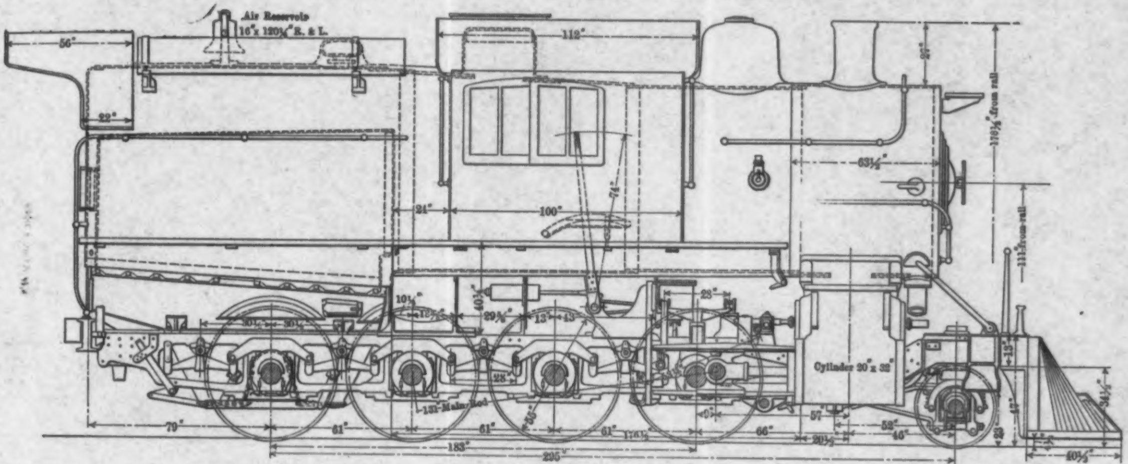
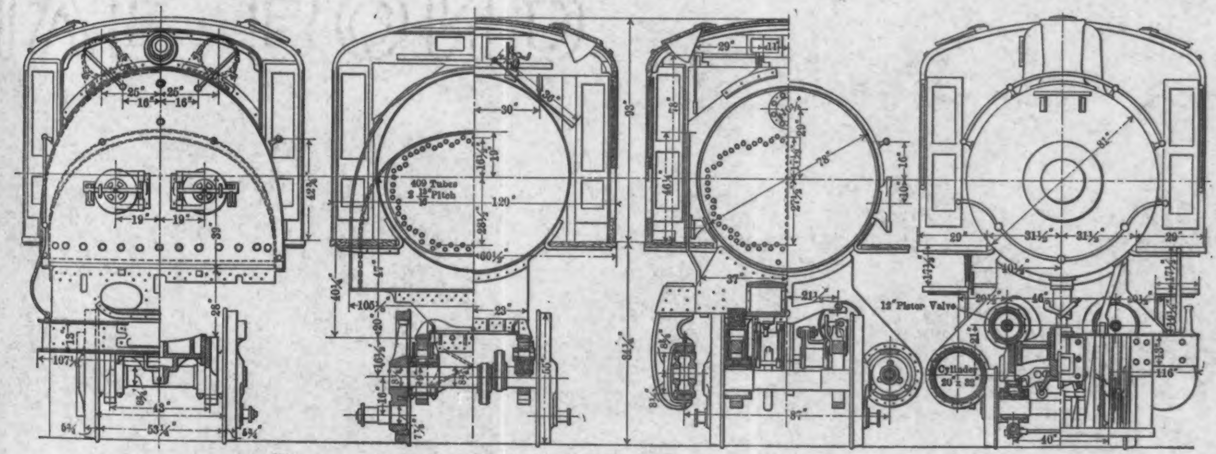
CONSOLIDATION LOCOMOTIVE. CENTRAL RAILROAD OF NEW JERSEY.

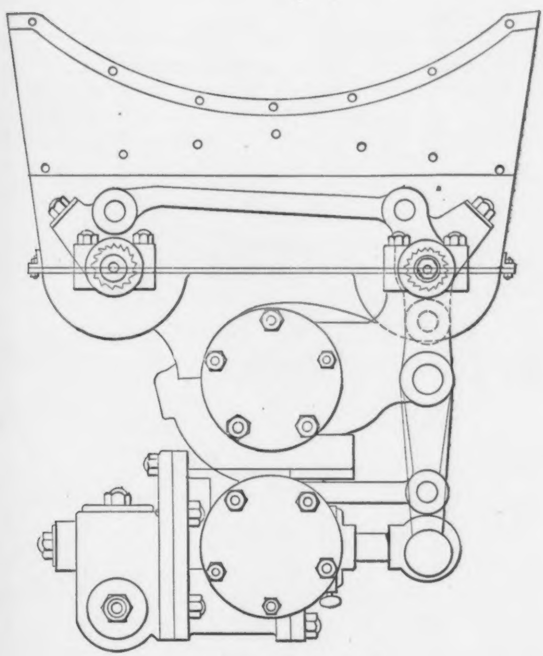


ELEVATION.



END VIEWS AND CROSS-SECTIONS.

heavy type, on warm days, it is almost impossible for one man to fire an engine over a long division, the result being frequent steam failures and constant reduction of train tonnage, which prevents us from receiving the full benefit of the increased size of our motive power. By the gravity-feed arrangement the hopper of the



END VIEW OF DAY-KINCAID STOKER.

FIG. 41.

stoker is supplied with coal, and consolidation engines have been operated 55 miles without the fireman handling a shovel of coal. A further improvement consists in a trough running from the stoker back into the coal space, and this is given a reciprocating movement by an arm attached to the tender axle. This relieves the

fireman from handling any coal and carries it mechanically to the hopper."

Mr. Vauclain, Superintendent of the Baldwin Locomotive Works, says:

"I have watched the performance of this stoker on the Chesapeake and Ohio Railroad, and feel that it is the coming device for locomotives and that the stoker in a short time will be sufficiently perfected to warrant its adoption and use by a great many railroads in this country where an excessive amount of coal must be shoveled by the fireman. If the present stoker does not have a sufficient capacity, a twin stoker could be fitted to wide firebox engines, which will successfully maintain steam under any conditions of service. I do not know of any locomotive device which

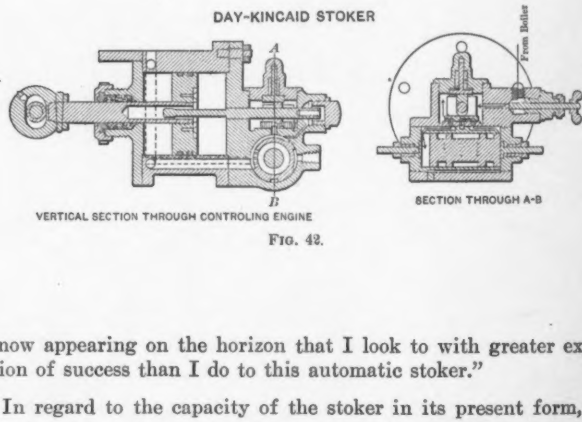


FIG. 42.

is now appearing on the horizon that I look to with greater expectation of success than I do to this automatic stoker."

In regard to the capacity of the stoker in its present form, the manufacturers advise that as a result of a recent test the full capacity of the conveyors was found to be 8 000 lb. per hour, and they believe it to have sufficient capacity to fire any locomotive now in use.

The foregoing refers to the Day-Kincaid locomotive stoker, manufactured in Cincinnati, Ohio, and it is the first successful stoker to be applied to locomotives.

As automatic stokers are likely to have an important relation

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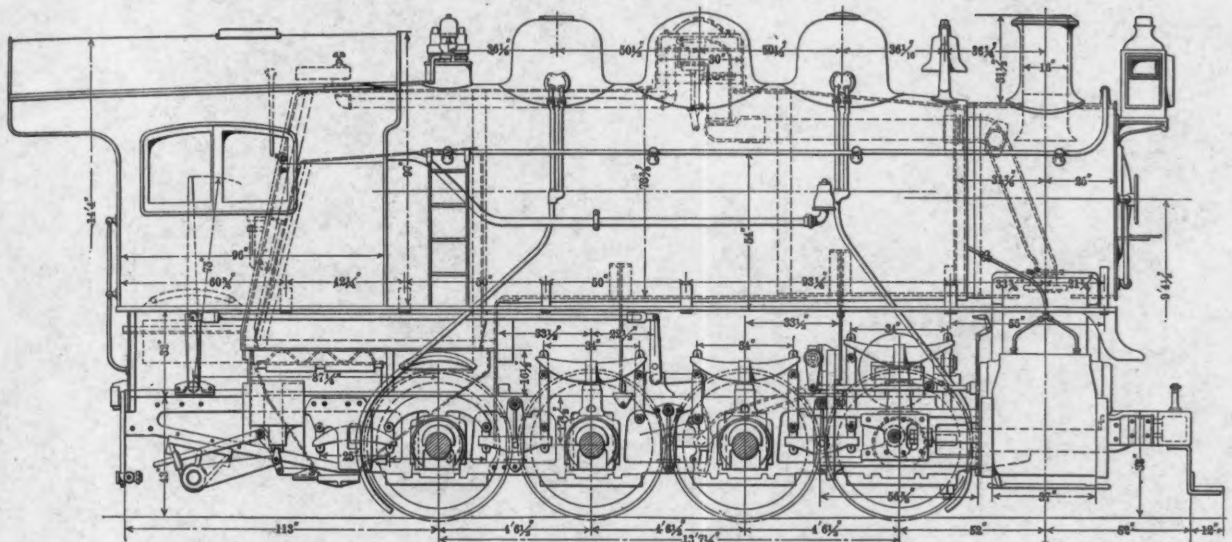
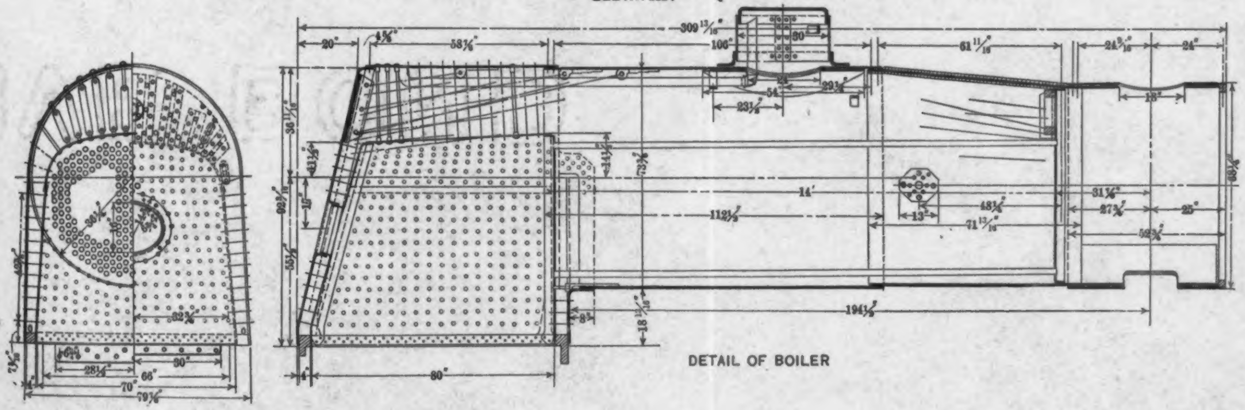
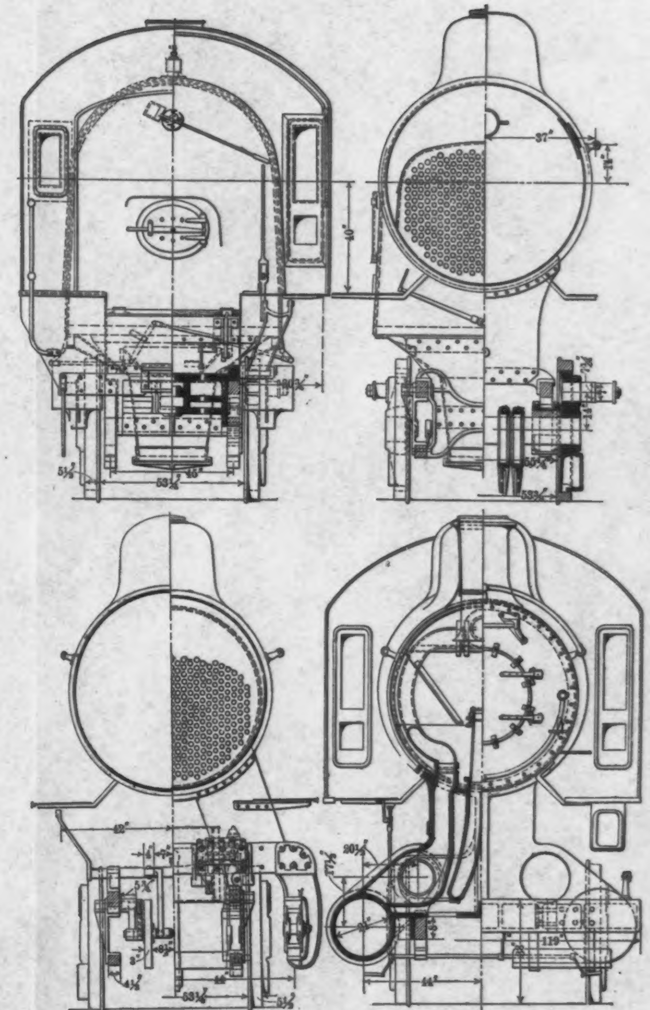
CHESAPEAKE AND OHIO EIGHT-WHEEL SWITCHING LOCOMOTIVE



ELEVATION



DETAIL OF BOILER



END VIEWS AND CROSS SECTIONS.

to the further development of the locomotive, it may be interesting to those not familiar with it to examine the Day-Kincaid stoker.

Piston Valves.

The flat slide valve is almost always provided with balancing strips, but, on account of imperfect lubrication, its excessive friction makes it difficult for the engine driver to change the cut-off, and the want of sufficient rigidity in the ordinary design has led to the use of a very heavy valve gear on modern locomotives. The piston valve was introduced for the purpose of securing a balanced valve, thus reducing valve friction. It has been designed in various forms, and much experimental work has been done with packing rings of different shapes. Although many objections have been made to the piston valve on account of broken packing rings and leakage, yet it has been gradually developed and successfully applied, so that it may be regarded as well established practice in America.

The use of the piston valve has modified materially the design of the cylinder and saddle, as well as the front frames, and in such designs there is opportunity to make a stronger construction of both cylinder and frame than with the flat valve. The packing rings used by the Baldwin Locomotive Works are rectangular and nearly square. The construction used by the American Locomotive Company for packing rings includes a bushing with L-shaped rings on each side of it, and a large number of locomotives are now running with this form of packing ring.

The principal objection which has been urged against the piston valve is the loss due to leakage, and it was supposed that this was much greater than with flat valves. The subject was carefully investigated by a committee of the Master Mechanics' Association, and the following figures are taken from a report presented at the convention of that association in June, 1904. The amount of leakage per hour was measured with each type of valve, one series with valves at rest and another with valves in motion. The best results obtained from piston valves show a leakage of 268 lb. per hour, and from flat valves, 348 lb. The worst cases of leakage were 2 880 lb. with piston valves and 2 610 lb. with flat valves.

Incidentally, it was found that the principal cause of leakage was poor fitting of the rings, and the conclusion was reached that if equal attention is given to each kind of valve, the piston valve would show less leakage. Flat valves are free to lift from the seat, and thus relieve the cylinders from water and undue compression, but piston valves cannot lift, and provision must be made for the rapid removal of water from the cylinder; therefore it is regarded as essential that relief valves and well-designed by-pass valves be used in connection with piston valves.

The question of the lubrication of piston valves while drifting is one which is still in the experimental stage, but it is also one to which proper attention must be given, in order to make the use of such valves entirely satisfactory.

Valve Gear.

The use of the Walschaert valve motion on the Baltimore and Ohio, Mallet articulated locomotive, and on the Pennsylvania Railroad's de Glehn 4-cylinder compound, exhibited at the World's Fair, Saint Louis, has again brought the merits of this gear to the attention of American designers. These two locomotives represent extreme conditions as to the speeds for which they are intended. The one is for slow speed on heavy grades, the other for high-speed passenger work. This would indicate that the Walschaert gear is well adapted to any kind of service—freight or passenger. It is fortunate that a well-designed gear of this type will soon be seen in operation in the United States, and its performance on these locomotives will be watched with interest.

This gear has been used for many years on the State Railways of Belgium, and it is also used extensively in Germany and France. In the latter country it has been given preference over all others for the high-speed balanced compounds, which have made such remarkable records, and, on this account, it is found on the French locomotive which was built for the Pennsylvania Railroad.

The chief difference between the Walschaert and the Stephenson motions is the constant lead with the former when the valve travel is changed. This is due to the fact that at the end of the

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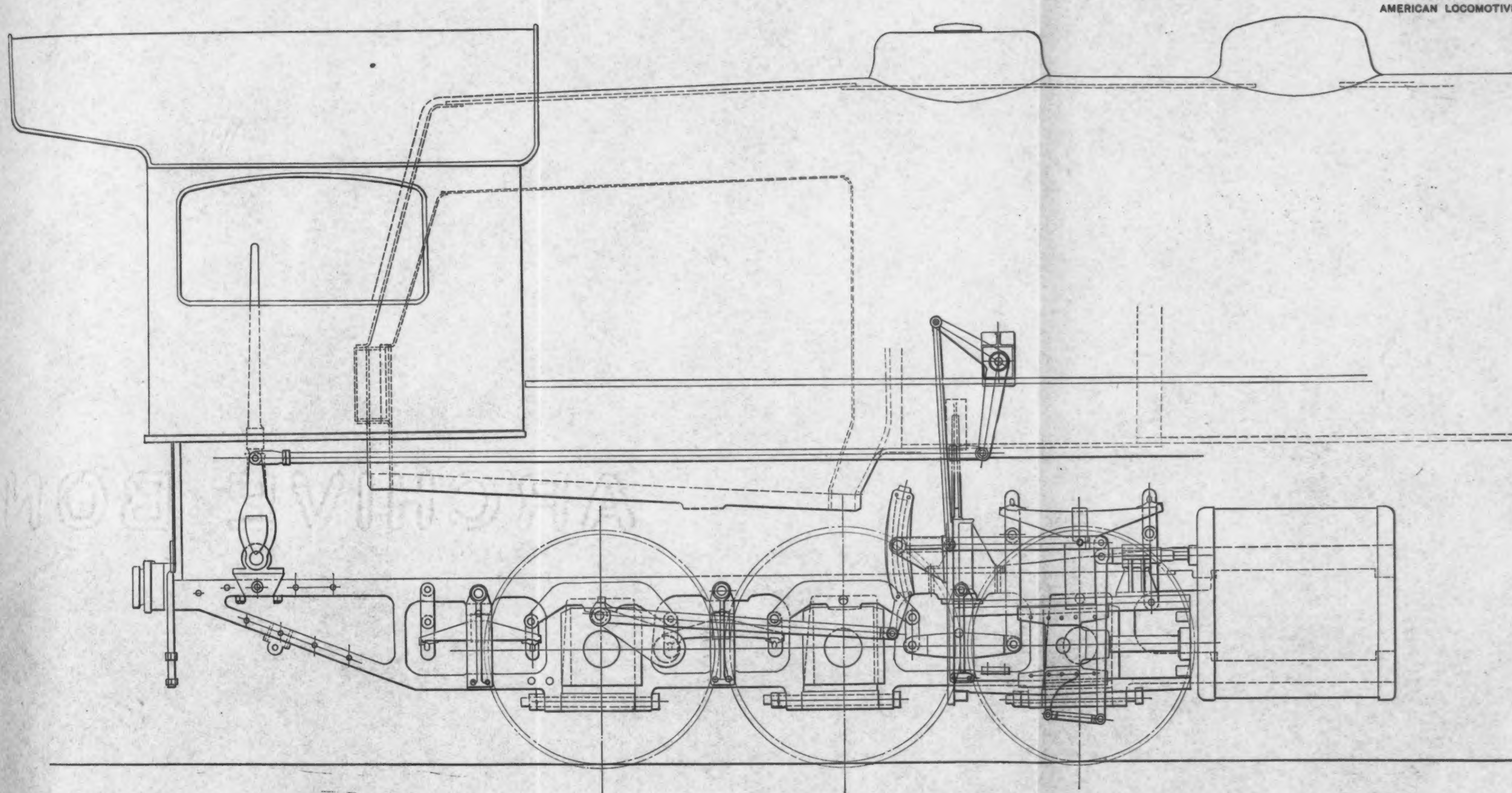

WALSCHAERT VALVE GEAR.

stroke the cross-head alone is responsible for the position of the valve, and as the cross-head always has the same position at the end of the stroke the valve will also have a definite location, and the travel may be decreased but the lead remains constant. For high-speed locomotives, of the ordinary simple 2-cylinder type, the constant lead may not be regarded as desirable, as early cut-offs are then used, and it is necessary to have greater pre-admission, when the cut-off is so short, in order to permit the steam to enter the cylinder without excessive wire-drawing. With the 4-cylinder balanced compound, which is the most promising type for high-speed work, the cut-off need not be short. The record of the indicator cards taken from a locomotive of this kind on the Northern Railway of France, as given in Mr. Sauvage's paper, shows that at 77 miles per hour the cut-off was 45% in the high-pressure cylinder and 67% in the low-pressure cylinder. The Joy valve gear has a constant lead, and it is used quite generally in England in connection with inside cylinders, and it has not been found objectionable on account of this peculiarity. As far as the distribution of steam is concerned, the Walschaert valve motion will produce results as good as, if not better than, the Stephenson shifting link, and it has some mechanical advantages which should recommend it as well adapted to modern locomotive practice in the United States.

A valve gear outside of the frames is conveniently inspected and repaired, while one inside of the frames is certainly in an awkward position for either operation. With inside cylinders and crank axles there is little room for eccentrics and links, and if all this be removed it allows ample length for main pin bearings, and it is then possible to have an inside bearing for the crank axle. The Walschaert gear, as ordinarily designed, is not symmetrical in a vertical plane, and there is a tendency to lateral bending and unequal wear when so constructed. In the engine referred to, Mr. de Glehn has taken special care to avoid these objections, and his design shows well-balanced wearing surfaces of ample proportions, which should be quite durable.

The point to which the writer wishes to call particular attention is the great contrast in the weight of the moving parts and the size of the bearings when this Walschaert outside gear is compared with similar parts of a Stephenson link motion driven by eccentrics. A

prominent superintendent of motive power, who has made a special study of indicator cards, and who has given much attention to valve gears, in a recent discussion on "Modern Tendencies in Locomotive Design in America," made this statement:

"I consider that the increased complication and weight of the valve motion is an exceedingly serious matter in giving distorted steam distribution, due to the destructive effect of the valve motion in causing wear and tear."

The reports on "Weights of Detail Parts of Locomotives"* give the weights of parts of the Stephenson valve gear for large locomotives, as follows, in pounds: Eccentric 212, eccentric strap 225, eccentric rod 125, link 148, rocker arm 248, transmission bar 128, valve rod 66, valve yoke 90, valve 211. These figures indicate that the Stephenson valve gear, including the eccentrics and straps, as found on modern locomotives, has become a very ponderous affair. Some attention has been given to the valve pattern, in the effort to make it as light as possible, but the same care has not been taken with the moving details connected with it, and which easily become a disturbing factor at high speeds if made too heavy.

The principal load which comes on the eccentrics and straps, causing them to heat, is not the friction of the valve, but it is that due to the inertia of the reciprocating parts of the valve gear, the motion of which is reversed twice for every revolution. If the rocker arm is included, the weight, as found above, of the moving parts from valve to eccentric strap for one cylinder is 1 052 lb., and at high speeds the energy of this moving mass must impose a heavy load on the eccentrics.

The eccentrics and straps are the most difficult details in the locomotive machinery to keep lubricated properly, and it requires constant vigilance to prevent them from heating. When they do heat and cut, and the straps are taken down, their location inside the frames is the most inconvenient possible, and with the increasing weight of the machinery this part of the locomotive repairs has become very laborious and expensive. More attention should be given to the reduction of the weight of the moving parts of the Stephenson valve gear, or some other type should be used. The Walschaert gear, located outside the frames, is easily accessible,

* *Proceedings*, Master Mechanics' Association, 1903, p. 187.

and very convenient for inspection, lubrication and repairs. The main driving bearings are two small pins with bushed bearings, and the contrast with the heavy and cumbersome eccentrics and straps, which are their equivalent in a valve gear system, is very striking. This gear is simple and light throughout, and it has much in it to be recommended for overcoming the objectionable features of the shifting link motion driven by eccentrics.

Locomotive Frames.

In the design of locomotive frames the bar frame is still the general practice, and, for the pedestal portion, it does not seem feasible to adapt any other form to the general design of American locomotives. With trailing wheels, double-plate frames are frequently used, the plates being 13 in. deep, the inner one $1\frac{3}{4}$ in. thick and the outside one $1\frac{1}{4}$ in. In one design, a deep plate, 2 by 32 in., is used between the cylinder and the saddle, but this portion is either forged or cast with the usual bar extending to the pedestals. In a double-bar front frame, the top bar extends back over the front pedestal. A great deal of study has been given to frame design, but broken frames are as frequent as ever, and their repairs, due to such fractures, are expensive. No satisfactory explanation or remedy for broken frames has been found, but the following have been suggested: First, poor design; second, imperfect welds or faulty material; third, the inertia of the boiler with reference to frames when the bumpers strike an obstruction or when brakes are applied suddenly, where high cylinder saddles are used; fourth, the presence of water in the cylinders, with piston valves and inefficient relief valves. While any one of these may not cause broken frames, yet they are contributory, and when several are acting at once they produce stresses greater than the resistance of the material. The cracks in frames are not confined to any definite locality, but appear at all pedestals, and as many back of the leading axle as in front of it. The fractures are also found as frequently in the full section as at bolt holes.

More locomotive frames are now made of cast steel than of forged iron, and steel is regarded as the better material for this purpose. The tensile strength is 75 000 lb. per sq. in., as compared

with 50 000 lb. per sq. in. for hammered iron. The cast-steel frame contains no welds, and is uniform in quality throughout its length. The projections required for driver-brake details, bearings, etc., for the valve motion, are conveniently cast in steel, but they complicate the forging when made of iron.

While steel is 50% stronger than iron, yet almost as many cast-steel as wrought-iron frames have broken, where similar conditions, as to design and service, have prevailed. The reason of this is probably due to a lack of annealing, or improper annealing, or overheating of the casting. It is evident that the proper heat treatment of cast-steel frames is not well understood, or it is not usually applied. The quality of steel which should be used for locomotive frames is indicated by the following specification:

Tensile strength, from 65 000 to 75 000 lb. per sq. in.;
Elongation in 2 in., not less than 15%;
To be annealed thoroughly.

Chemical composition desired:

	Acid.	Basic.
Carbon	0.28	0.35
Phosphorus	0.05	0.06
Sulphur	0.05	0.06
Manganese	0.60	0.70

One advantage of cast-steel frames is the rapidity with which they can be manufactured; and they are also convenient for railroads which do not possess heavy hammers suitable for forgings of this size. Cast-steel frames require some work in straightening in the smith shop before they are ready for the planer. The cost of machining is also high, on account of the rough and hard surface, but the total cost finished is not more than two-thirds that of forged-iron frames. The foregoing information on frames is obtained partly from a report of a Committee of the American Railway Master Mechanics' Association, June, 1904. This committee recommended as remedies for broken frames the following:

1.—Rational design;
2.—Cast steel to proper specification and good annealing;

3.—Provide such bracing as will prevent "weaving" (that is, movement of one side independent of the other); the bracing should be designed so that the bending will be synchronous;

4.—The clip pedestal binder is preferable to thimble and bolt;

5.—Cylinders should be drained properly.

Locomotive Performance.

Few reliable tests of modern locomotives have been made, and it is difficult to get accurate data as to their performance. The tests which are now being conducted by the Pennsylvania Railroad Company, in their plant in the Transportation Building, St. Louis, are the most comprehensive ever attempted, and they promise to show the most valuable results ever obtained by such methods. They are the only laboratory tests which have been made with the large locomotives representing present practice, and, as the reports are not now available, they are here recommended for future reference to those interested in the most refined measurements of locomotive performance.

An example of heavy freight work is shown by the performance of the Lake Shore consolidation engine, which has hauled from Youngstown to Ashtabula, 59 miles, 86 loaded coal cars weighing 5 600 tons, in 5 hours. The grades on this division do not exceed 0.3 per cent.

An indication of the capacity of large passenger locomotives may be had from the performance of those handling the Alton trains between Chicago and St. Louis, where the engines of the Atlantic type haul nine cars, weighing 500 tons, at an average speed of 46 miles per hour. These engines weigh 183 800 lb., and the weight on the four drivers is 103 700 lb. The engines of the Pacific type, on the same road, haul twelve cars, weighing, with passengers and baggage, 675 tons, on the same schedule of 46 miles per hour. These engines have a total weight of 219 000 lb., with 141 700 lb. on six drivers.

In conclusion, the writer must apologize for this imperfect and incomplete account of the American Locomotive of the present day, but the subject is so comprehensive that it must have some limitations in a paper of this nature, and the writer has been content to

take this opportunity of placing on record descriptions of the best American practice in locomotive construction at the time of the St. Louis Exposition of 1904, and to discuss some of the principal changes which have taken place in this practice since the World's Fair at Chicago in 1893.

The following locomotives, with their details, are illustrated in this paper:

Passenger Locomotives.

Four-cylinder balanced compound; Atchison, Topeka and Santa Fe Railway; Baldwin Locomotive Works. Figs. 1, 2, 3, 4, 5 and 6; also Fig. 1, Plate VI.

Four-cylinder balanced compound; Chicago, Burlington and Quincy Railroad; Baldwin Locomotive Works. Figs. 8 and 9; also Fig. 2, Plate VI.

Four-cylinder balanced compound; New York Central and Hudson River Railroad; American Locomotive Company. Figs. 10, 11, 12, 13 and 14; also Fig. 1, Plate VII, and Plate VIII.

Simple Atlantic type; Pennsylvania Lines; American Locomotive Company. Figs. 15, 16 and 17; also Fig. 2, Plate VII and Plate IX.

Simple Pacific type; New York Central and Hudson River Railroad; American Locomotive Company. Figs. 18 and 19; also Fig. 1, Plate X and Plate XI.

Simple Atlantic type; Chicago & Alton Railway; Baldwin Locomotive Works. Fig. 20; and Fig. 2, Plate X.

Freight Locomotives.

Simple consolidation; Lake Shore and Michigan Southern Railway; American Locomotive Company. Figs. 21, 22, 23, 24, 25, 26, 27 and 28; also Plates XII and XIII.

Tandem compound; Atchison, Topeka and Santa Fe Railway; Baldwin Locomotive Works. Figs. 29, 30, 31, 32, 33 and 34; also Fig. 1, Plate XIV.

Mallet articulated compound, twelve-wheel; Baltimore and Ohio Railroad; American Locomotive Company. Figs. 35, 36 and 37; also Fig. 2, Plate XIV and Plate XV.

Simple consolidation anthracite; Central Railroad of New Jersey; American Locomotive Company. Figs. 38 and 39; also Fig. 1, Plate XVI and Plate XVII.

Simple eight-wheel switching locomotive; Chesapeake and Ohio Railroad; American Locomotive Company. Fig. 2, Plate XVI and Plate XVIII.

Day-Kincaid Stoker. Figs. 40, 41 and 42.

Walschaert valve gear for Baltimore and Ohio Mallet articulated locomotive. Plate XIX.

TABLE 1.—PRINCIPAL DIMENSIONS OF

Items.	Pennsylvania Lines. Atlantic Locomotive. Class E 2 a.	New York Central. Pacific Type.	Chicago and Alton. Atlantic Locomotive.
CYLINDERS:			
Diameter	$20\frac{1}{2}$ in.	22 in.	20 in.
Stroke	26 "	26 "	28 "
BOILER:			
Outside diameter of first ring	67 "	$72\frac{1}{16}$ "	70 "
Working pressure	205 lb.	200 lb.	200 lb.
FIREBOX:			
Length	111 in.	$96\frac{1}{2}$ in	$108\frac{1}{2}$ in.
Width	72 "	$75\frac{1}{4}$ "	$72\frac{1}{4}$ "
Tubes:			
Number	315	303	326
Diameter	2 in.	$2\frac{1}{4}$ in.	$2\frac{1}{4}$ in.
Length over tube sheets	15 ft. 1 in.	20 ft.	16 ft.
HEATING SURFACE:			
Tubes	2 474 sq. ft.	3 554 sq. ft.	3 056 sq. ft.
Water tubes	....	....	....
Firebox	165.7 sq. ft.	....	191.2 sq. ft.
Total	2 639.7 " "	3 758 sq. ft.	3 247.2 " "
Grate surface	55.5 " "	50.2 " "	54.2 " "
VALVES:			
Greatest travel	7 in.	6 in.	....
Outside lap	$1\frac{5}{8}$ "	1 "	....
Inside clearance	$\frac{3}{32}$ "	$\frac{1}{8}$ "	....
Lead in full gear	$\frac{1}{32}$ "	0	....
Kind of gear	....	....	....
SIDE ROD CRANK PIN JOURNALS:			
Diameter	$5\frac{1}{2}$ in.	5 in.	....
Length	$4\frac{1}{2}$ "	$4\frac{3}{4}$ "	....
DRIVING WHEELS:			
Diameter	80 in.	75 in.	80 in.
Journals: Diameter and length	$9\frac{1}{2}$ x 13 in.	....	10 x 12 in.
Main crank-pin journals	....	$7\frac{1}{2}$ x $6\frac{1}{2}$ in.	....
TRAILING WHEELS:			
Diameter	50 in.	50 in.	48 in.
Journals	....	8 x 14 in.	8 x 12 in.
ENGINE TRUCK:			
Journals	$5\frac{1}{2}$ x 10 in.	$6\frac{1}{4}$ x 10 in.	$6\frac{1}{2}$ x $12\frac{1}{2}$ in.
WHEEL BASE:			
Driving	7 ft. 5 in.	13 ft.	7 ft. 8 in.
Total engine	30 " $9\frac{1}{2}$ "	33 ft. $7\frac{1}{2}$ in.	27 " 0 "
TENDER:			
Weight, empty	56 150 lb.	52 400 lb.	....
Water capacity	7 000 gal.	6 000 gal.	8 400 gal.
Coal capacity	10 tons.	10 tons.	....
Diameter of wheels	36 in.	36 in.	36 in.
Journals: Diameter and length	$5\frac{1}{2}$ x 10 in.	$5\frac{1}{2}$ x 10 in.	$5\frac{1}{2}$ x 10 in.
WEIGHT:			
Engine in working order	176 000 lb.	218 000 lb.	183 000 lb.
On drivers	109 000 "	140 500 "	103 690 "
Engine and tender, in working order.	311 100 "	340 400 "	340 000 "

TYPICAL AMERICAN FREIGHT LOCOMOTIVES, 1904.

Lake Shore. Consolidation Locomotive.	Santa Fé 2-10-2 Type. Tandem Compound.	Mallet Articulated Compound. 0-6-6-0 Type.	Central of New Jersey. Consolidation.	Chesapeake and Ohio. 8-wheel Switching Locomotive.
23 in.	19 and 32 in.	20 and 32 in.	20 in.	21 in.
30 "	32 in.	32 in.	32 "	28 "
80 "	78¾ "	84 "	78 "	67 "
200 lb.	225 lb.	235 lb.	200 lb.	200 lb.
109 in.	108 in.	108 in.	123 in.	80 in.
74 "	78 "	96 "	97 "	70 "
460	391	436	409	351
2 in.	2¼ in.	2¼ in.	2 in.	2 in.
15 ft. 6⅜ in.	20 ft.	21 ft.	13 ft. 10¼ in.	14 ft.
3 725 sq. ft.	4 586 sq. ft.	5 366 sq. ft.	2 972 sq. ft.	2 572.97 sq. ft.
29 " "	....	....	....	....
203 " "	210 sq. ft.	219 sq. ft.	200 sq. ft.	132.13 sq. ft.
3 957 " "	4 796 " "	5 585 " "	3 172 " "	2 705.10 " "
55 " "	58.5 " "	72 " "	82 " "	38.9 " "
5 7/16 in.	....	6 in.	5 25/32 in.	5½ in.
1 "	....	H. P. 1⅛ in., L. P. 1 in.	1 "	1 "
0 "	....	H. P. ¼ " L. P. ¼ "	0 "	0 "
1/16 "	....	H. P. ⅛ " L. P. ⅛ "	— 1/16 "	0 "
....	....	Walschaert.	....	....
8¼ in.	....	9 in.	6½ in.	7¼ in.
5½ "	....	13 "	6½ "	5½ "
57 in.	57 in.	56 in.	55 in.	51 in.
9½ and 10 x 12 in.	11 x 12 in.	9 x 13 in.	9 x 12 in.	9 and 9½ x 10 in.
7½ x 7 in.	....	....	6½ x 6½ "	7 x 6½ in.
....	....	....	....	....
....	....	....	....	....
6 x 12 in.	7½ x 12 in.	....	6½ x 12 in.	....
17 ft. 3 in.	19 ft. 9 in.	....	15 ft. 3 in.	13 ft. 7½ in.
26 " 5 "	35 " 11 "	30 ft. 8 in.	24 " 7 "	....
56 580 lb.	....	....	55 460 lb.	52 400 lb.
7 500 gal.	8 500 gal.	7 000 gal.	7 000 gal.	6 000 gal.
16 tons.	....	13 tons.	12 tons.	7 tons.
33 in.	34½ in.	....	....	....
5½ x 10 in.	5½ x 10 in.	....	5½ x 10 in.	5½ x 10 in.
235 400 lb.	287 240 lb.	334 500 lb.	208 000 lb.	....
207 000 "	234 580 "	334 500 "	186 000 "	171 175 lb.
386 400 "	450 000 "	477 500 "	350 000 "	292 325 "

TABLE 2.—PRINCIPAL DIMENSIONS OF THREE BALANCED COMPOUND LOCOMOTIVES.

Items.	Santa Fé Balanced Compound.	New York Central Four-Cylinder Compound.	C. B. & Q. R. R. Four-Cylinder Balanced Compound.
CYLINDERS:			
Diameter	15 and 25 in.	15½ and 26 in.	15 and 25 in.
Stroke	26 in.	26 in.	26 in.
BOILER:			
Outside diameter of first ring.	66 in.	72¼ "	64 "
Working pressure	220 lb.	220 lb.	210 lb.
FIREBOX:			
Length	107 15/16 in.	96⅛ in.	96⅛ in.
Width	66 "	75¼ "	66¼ "
Thickness of plates:			
Sides, back and crown.	⅜ "	⅜ "	⅜ "
Tube sheet	9/16 "	½ "	½ "
Tubes: Material	Iron.	Iron.	Iron.
Number	273	390	274
Gauge	No. 11.	No. 11.	No. 11.
Diameter	2¼ in.	2 in.	2¼ in.
Length	18 ft. 1 in.	16 ft.	19 ft.
HEATING SURFACE:			
Tubes	2 893 sq. ft.	3 248.1 sq. ft.	3 050.5 sq. ft.
Firebox	190 " "	175 " "	166.4 " "
Total	3 083 " "	3 446.1 " "	3 216.9 " "
Grate area	49.5 " "	50.3 " "	44.14 " "
VALVES:			
Diameter	15 in.	14½ in.	15 in.
Greatest travel of slide valves.	5 "	6 "	5½ "
Outside lap " " "	H. P. 1 in., L. P. ⅞ in.	1 "	H. P. ⅞ in., L. P. ¾ in.
DRIVING WHEELS:			
Outside diameter	73 in.	79 in.	78 in.
Journals: Main	10 x 11 in.	10 x 12 in.	10 x 10½ in.
Others	9 x 12 "	Front, 6½ x 12 in.	9½ x 12 "
TRAILING WHEELS:			
Diameter	44 in.	50 in.	48 in.
Journals	8 x 12 in.	8 x 14 in.	8 x 12 in.
ENGINE TRUCK:			
Journals	6 x 10 in.	6½ x 12 in.	6 x 10 in.
WHEEL BASE:			
Driving	6 ft. 4 in.	7 ft. 0 in.	7 ft. 3 in.
Rigid	15 " 0 "	16 " 6 "	5 " 6 "
Total	29 " 6 "	27 " 9 "	30 " 2 "
TENDER:			
Water capacity	8 400 gal.	6 000 gal.	6 000 gal.
Coal capacity	12 tons.	10 tons.	10 tons.
Journals	5½ x 10 in.	5½ x 10 in.	5 x 9 in.
WEIGHT:			
On driving wheels	101 420 lb.	110 000 lb.	100 000 lb.
On truck, front	46 920 "	....	50 000 "
On trailing wheels	45 420 "	....	42 000 "
Total engine	193 760 "	200 000 lb.	192 000 "
Total engine and tender, about	348 000 "	321 000 "	312 000 "

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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Paper No. 53.

LOCOMOTIVES AND OTHER ROLLING STOCK.

ROLLING STOCK IN FRANCE.

By Edouard Sauvage.*

Locomotives.

The interest of French locomotive practice is centered in the development of the four-cylinder compound, which has permitted a marked increase in the weight and speed of the trains. In the majority of these engines, the high-pressure cylinders drive one axle, and the low-pressure cylinders another axle, but coupling rods have been preserved between these axles. The only exception is a unique locomotive (No. 701) built in 1885 for the Chemin de Fer du Nord, in which the two axles were not connected. This plan has not been continued. The use of coupling rods began in 1887 on the Paris, Lyons, et Méditerranée Railway locomotives. Since 1890 large numbers of such engines have been built or ordered by French railway companies, and their aggregate number will soon exceed two thousand.

Mallet, four-cylinder engines are used on meter-gauge lines.

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These are supported on two separate groups of coupled axles: One group, driven by the high-pressure cylinders, is connected to the locomotive frame in the ordinary way; the other group, driven by the low-pressure cylinders, forms a movable truck, so as to give great flexibility to the engine.

A few Vauclain locomotives, built in America, are in use on the State Railways (also non-compound American locomotives on these and other railways); and old engines have been converted into two-cylinder compounds, especially on the Midi lines. Steam pressures of from 14 to 16 kg. per sq. cm. (200 to 230 lb. per sq. in.) are resorted to, the use of very high pressures being requisite, when it is necessary to combine power and lightness, as in locomotive engines.

The majority of the compound engines belong to two classes, which may be considered as standards in France: The express locomotive, with four large coupled wheels, of 2 m. (6 ft. 6¾ in.) diameter or a little more, and the six-coupled locomotive, with diameters of from 1.600 m. to 1.750 m. (5 ft. 2$\frac{15}{16}$ in. to 5 ft. 8⅞ in.), both being fitted with a bogie in front. The six-coupled locomotives are equally fit for goods and for ordinary passenger trains. A tendency must be noticed to increase the diameter of the six-coupled wheels of these engines to about 2 m. (6 ft. 6¾ in.), to enable them to work express trains. For instance, this has recently been done on the Eastern, Paris, Lyons and Mediterranean, and Western Railways. On the other hand, the "Atlantic" type is resorted to for increasing the power of express locomotives, the boiler, and particularly the firebox, being enlarged.

The new "Atlantic" (Nos. 3001-3008), recently built for the Paris-Orléans Railway by the Société Alsacienne de Constructions Mécaniques, is of special interest as being the most powerful express locomotive yet made for the French lines. The principal dimensions are given in Table 3.

The adhesive weight is 36 *t** (18 *t* per axle), and it is expected that this weight will be increased to 40 *t*. Such a change is easy in locomotives of this type.

The following figures, extracted from the dynamometer car

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* This abbreviation *t* is used for the French "tonne."

records and indicator cards taken during numerous runs of these engines with heavy express trains, give a fair idea of their power:

A length of 13 km. (8 miles) was traversed in 419 seconds, being at a rate of 112 km. an hour (70 miles). The cut-off was at 53 and 65%, respectively, in the high- and low- pressure cylinders. The mean draw-bar pull, behind the tender, was 2 350 kg. (5 180 lb.), from which results an average effective horse-power of 972;* the mean indicated horse-power was 1 830. The maximum indicated horse-power recorded on these engines was 1 900.

TABLE 3.—Principal Dimensions of "Atlantic" Locomotives of the Paris-Orléans Railway.

Boiler:	
Internal diameter	1.513 m. (4 ft. $11\frac{1}{2}$ in.)
Height of axis above rail	2.700 m. (8 ft. $10\frac{5}{16}$ in.)
Working pressure	16 kg. per sq. cm. (228 lb. per sq. in.)
Tubes:	
Length between plates	4.400 m. (14 ft. $5\frac{3}{16}$ in.)
External diameter	70 mm. ($2\frac{3}{4}$ in.)
Number (ribbed tubes)	139
Grate area	3.1 sq. m. ($33\frac{3}{8}$ sq. ft.)
Heating surface	239.4 sq. m. (2 577 sq. ft.)
Cylinders:	
H. P. diameter	360 mm. ($14\frac{3}{16}$ in.)
Stroke	640 mm. ($25\frac{1}{8}$ in.)
Cylinders:	
L. P. diameter	600 mm. ($23\frac{5}{8}$ in.)
Stroke	640 mm. ($25\frac{1}{8}$ in.)
Driving wheels, diameter	2.040 m. (6 ft. $8\frac{5}{16}$ in.)
Weight:	
Total in working order	72 900 kg. (71.75 tons)

On the Nord Railway, "Atlantic" locomotives, with somewhat smaller dimensions, maintain a very fine express service. Average

* The unit of horse-power is here 75 kg. × 1 m. in a second, while the English unit is slightly greater. It might be advisable to express powers always in kilowatts, to do away with this cause of errors. In the present instances, the figures would be 715, 1 347 and 1 400 kw.

speeds, from end to end, of 90 to 100 km. an hour (56 to 62 miles), are obtained with trains weighing (exclusive of locomotive and tender) 250 to 300 tons. The profile of the lines is generally easy, with somewhat prolonged inclines of 5 mm. per m. (1 in 200), and, in a few places, of 8 mm. per m. (1 in 125). Some of these trains run in connection with boats from England, and, in many instances of bad weather, time lost by the boat has been made up by the train, although the schedule is calculated with a pretty fair speed.

For instance, the run from Calais to Paris (297.2 km. = 184.6 miles) has been made in 3 hr. 9 min. against a booked time of 3 hr. 30 min.; and, with a very light train, only 3 hr. 3 min. have been consumed from Paris to Calais. The run from Paris to St. Quentin (153.1 km. = 95.2 miles) has been made in 1 hr. 37 min. with a train weighing 365 *t* (359.2 English tons), and in 1 hr. 34 min. with a 300-*t* (295.2-ton) train.

The six-coupled compound of the Eastern Railway may be mentioned as a typical express locomotive of this class. After comparative trials with "Atlantic" locomotives, these six-coupled engines have been selected as more suitable to the requirements of the lines of this system. The grate area is 2.857 $m.^2$ (30$\frac{3}{4}$ sq. ft.), the heating surface, 223.94 $m.^2$ (2 410$\frac{7}{16}$ sq. ft.); the diameters of the cylinders are 350 and 560 mm. (13$\frac{3}{4}$ and 22 in.), with 660 mm. (26 in.) stroke; the diameter of the driving wheels is 2 090 m. (6 ft. 10$\frac{5}{16}$ in.). The engine, in working order, weighs 71.8 *t* (70.66 tons), of which 51 *t* (50.19 tons) is adhesive weight.

Although in many cases the six-coupled four-cylinder compounds have replaced with advantage the old eight-coupled locomotives, which were largely used in France, the Paris, Lyons, Méditerranée system has a large number of such engines with four cylinders, and a new type of eight-coupled four-cylinder compound has been built by the Southern Railway, and by the Eastern Railway.

In this last engine a pony truck is used in front of the cylinders. The four cylinders are placed on a line under the smokebox. The high-pressure cylinders are inside, and command the second coupled axle. The low-pressure cylinders are connected with the third axle. It is advisable, as far as possible, to put the low-pressure cylinders inside, under the smokebox; but in this case their

diameter was too large, and they could not be placed between the frames.

The consolidation locomotives haul trains of 800 to 900 *t* (exclusive of engine and tender) on lines with inclines of 1 cm. per m.; the same trains being taken by six-coupled engines on easy profiles. In the present state of things, the pull of these engines nearly comes up to what the car couplings can stand with safety, and could not be exceeded on that account.

Powerful tank-engines have been put in service recently, or are in course of construction, for working suburban trains, and even for general service, a rapid acceleration being of great importance in the first case.

These tank-engines have six coupled wheels with a pony truck, and, in some instances, a bogie at both ends, or eight coupled wheels with one bogie in front; this last type is intended mainly for goods traffic. The four-cylinder compound system is also used for these engines.

The advantages of the four-cylinder compound system, as resulting from a prolonged practice in France, may be summed up as follows:

Economy of coal resulting from the compound system in itself, or increase of power with the same consumption of coal;

Good utilization of steam at very high pressure, with the simple or piston valve and the old gears;

Good balance of pistons and other pieces with reciprocating motion; counterweights applied only for revolving parts, thus doing away with vertical variations of pressure and pounding action on rails;

Ample bearing surfaces for all parts of mechanism, owing to the use of four cylinders with four separate gears and suppression of all undue strains.

It must be added that these compounds possess great elasticity in working, and are as well fitted for moderate as for high speeds, for light or for heavy trains. They remain economical within a wide range of power. In the Paris-Orléans Railway experiments, an average steam consumption of 10.5 kg. (23 lb.) per horse-power in an hour (the power being calculated from the action exerted

by the driving wheels on the rail, to compare precisely with what is called the effective power of a stationary engine) has been measured with trains of heavy and also moderate weight.

As regards details of construction, the nearly exclusive use of Serve or ribbed tubes in all new constructions is well worth mentioning. Experiments have proved that the efficiency of a given surface of Serve tubes, taking into account the whole metallic area in contact with hot gases, was about the same as with the same surface of plain tubes; and in practice, these tubes have been found durable and free from leakage. They must be kept free from ashes and soot by frequent cleaning with a steam jet and, when necessary, with scrapers.

For valve gears, the Walschaert system has been adopted in many of the French four-cylinder compounds, as well as for ordinary locomotives. This system is quite convenient when the valve is placed above or under the cylinder, and there is a distinct advantage in the use of one eccentric instead of two, for inside as well as for outside cylinders. The whole mechanism is simple, and easily kept in order. The distribution of steam effected by the Walschaert system is particularly good, and quite uniform on both sides of the piston at different points of cut-off.

Piston valves are used in some of the latest designs. After the experience on the Eastern Railway, they are preferable to flat valves, chiefly as giving larger ports and so reducing wire-drawing and compression of steam. An economy of coal, as high as 10%, has resulted from their use in some cases.

From prolonged experience and from the unanimity of opinion of all having experience with these engines, it may be taken for granted that the four-cylinder compound system possesses marked advantages, at least under the conditions of service prevailing on main French lines. Thanks to their use, French railways have been enabled to increase largely the weight and the speed of their trains, for goods as well as for passenger service, without any large increase of coal consumption per kilometer run. In fact, it is rather underestimating the merits of the compounds to say that by their use the weight of trains is increased by one-third with the same cost of fuel over what it was with the best simple engines used before; or.

if not the weight, speed is increased, and in many cases both weight and speed.

In other words, the compounds would take a traffic equal to four, against a traffic equal to three, the number of engines and the expenses for fuel and wages remaining the same. The initial cost of the compounds is higher, the expenses for repairs may be somewhat greater, but the increase of traffic is such that the economy is obvious. As regards the cost of repairs, there is still some doubt as to their exact amount, as a very large proportion of the compounds have been running for a few years only, but it must be remarked that the increase of expenses will very likely be due to the boilers working at a high pressure, and it seems that the same pressures would be necessary for simple engines, if they were to compete with compounds.

To this must be added, especially for passenger service, the advantages of greater speed, of more punctuality, and of dispensing in many cases with pilot engines or with supplementary trains. In a mere practical point of view, the French administrations feel satisfied with the great extension they gave to the four-cylinder compound system, from which resulted economy as well as a large improvement in their services.

A complete solution of the problem would require a proof that the same results might not be obtained in some other way. Available data are not sufficient to give such a proof in an incontestable manner; still, it seems difficult to build an ordinary locomotive quite equal in every respect to the latest compounds.

It is clear that simple two-cylinder engines might be made with the same large boiler, and work with the same high pressure, but it is nearly as clear that, with the ordinary valve gear of the locomotive, steam at such a high pressure cannot be utilized as well as by compounding; there is little doubt that the simple locomotive would require more steam for the same work or give less work for the same quantity of steam. In addition, there is a real difficulty in making all the parts of the simple engine strong enough to stand without undue wear the great stresses resulting from the increased pressure on large pistons, although this difficulty may be overcome.

An opinion, which seems to prevail, is that compound locomotives

may be economical during long runs, but that their advantage is lost when they stop and start frequently, owing to the direct admission of steam to the low-pressure cylinders at starting. This opinion is rather too dogmatic, and the question requires some consideration. In many cases, with four-cylinder compounds, the tractive power necessary for starting from rest is obtained without this direct admission, or steam is admitted in that way only for the very first revolution of wheels. The engine is then worked compound, but in full gear for all cylinders. Of course, steam is not so well utilized as with a proper degree of expansion in each cylinder, but, even in that case, the compound compares favorably with a simple locomotive working in full gear.

In conclusion, opinions expressed by men placed at the head of locomotive departments of French railways will be found of interest. Among others, M. Baudry, Locomotive Superintendent of the Paris, Lyons, Méditerranée system, ended a communication to the Société des Ingénieurs Civils as follows:

"Some people may be of opinion that the importance of the coal saving due to compound locomotives is small, and even vanishes when the prices of coal are very low. That is a mistake, as the saving of coal means really an increased power of the locomotive. In fact there is no saving of coal for a certain work performed, but there is more work for the same coal consumption; thence result other important savings; less locomotives, less drivers, less firemen, less trains are necessary for a given traffic. These aggregate savings, which do not depend upon the price of coal, greatly exceed, in the majority of cases, the saving of coal proper. If the weight of trains is not increased, then an acceleration in speed is possible, and in that way the construction of more economical locomotives has resulted, during the last few years, in an increase of speed on all French lines."

M. Salomon, Locomotive Superintendent of the Eastern Railway, writes that:

"Compared to the ordinary locomotive, the compound locomotive has the important advantage of a coal economy, which varies with the nature of the service, but which is, on an average, from 10 to 15 per cent. With the use of four cylinders the symmetry of the engine is preserved, inertia forces are in better equilibrium, the turning force is more uniform, the total work is divided between two axles, and stresses are more evenly distributed on the frame. As a conse-

quence, the mileages between two heavy repairs in the shops has been increased by 50 per cent.

"In my opinion, the use of these locomotives marks an important improvement, which has not been accompanied by any trouble in service; the only objections which have been often made to the use of compound locomotives are want of elasticity in their power, and excessive compression of steam at high speed. As regards the first objection, the use of independent gears for the high- and for the low-pressure cylinders allows a satisfactory distribution of steam under very different rates of weight and speed. The second objection vanishes with large clearances and sufficient area of steam passages on the low-pressure cylinders. In this respect piston valves will be quite suitable if they remain sufficiently tight."

Passenger Carriages.

Normal passenger carriages are of three different classes; to these must be added sleeping and saloon carriages.

All recent constructions (for main line traffic) are of the lateral-corridor type with compartments. In the best types of rolling stock, vestibules with covered gangways from carriage to carriage are used. Such is the case for first- and second-class coaches intended for through trains, and these are frequently carried on four-wheeled bogies.

In some other cases, especially for third-class, the corridor extends only inside one carriage, without communication with its neighbour; side doors are preserved, and these carriages are usually carried on two or three axles. They are all fitted with lavatories.

Sleeping cars are also of the compartment system, with two and sometimes four berths in a compartment.

For suburban traffic, the old system of compartments with side doors is still used; sometimes carriages with wide platforms at both ends are preferred.

Goods Wagons.

The standard wagons have two axles. The normal carrying capacity of 10 tons has been extended to 15 and even 20 tons in recent constructions. Steel bogie cars, carrying from 40 to 50 tons

of coal or dense materials, such as stones or ores, have been built recently. Their use is, as yet, limited.

Westinghouse brakes (and in some instances other compressed-air brakes) are used on the whole of the passenger stock and on certain goods wagons.

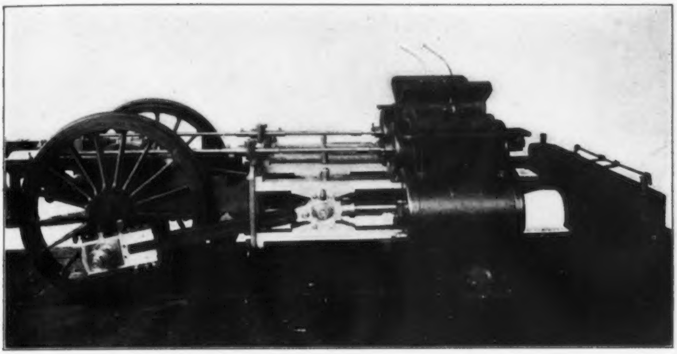

FIG. 1.—SIDE VIEW OF CYLINDERS AND DRIVING WHEELS.

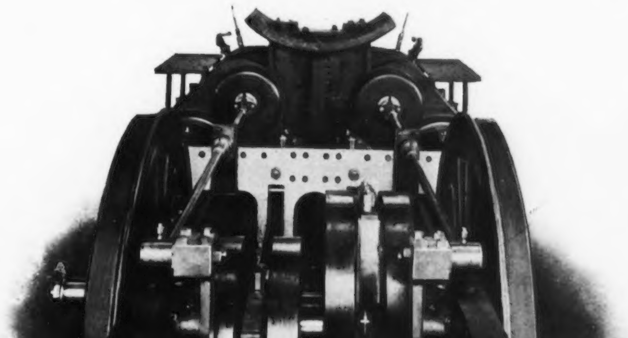

FIG. 2.—REAR VIEW OF CYLINDERS AND DRIVING WHEELS.

TRANSACTIONS

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LOCOMOTIVES AND OTHER ROLLING STOCK.

THE BALANCED COMPOUND LOCOMOTIVE.

By S. M. Vauclain, M. Am. Soc. M. E.*

The modern balanced compound locomotive is the product of evolution. It is the last link of a very interesting chain of inventions which comprises many types of engines actually built and, at the same time, a number of suggestions and designs, which in many cases were far ahead of their times and which were never put into service by those responsible for them.

Hornblower, 1781; Woolfe, 1804.—The compound principle was first brought forward in connection with pumping engines by Hornblower in 1781, and improved and adapted in 1804 by Arthur Woolfe. In both cases but two cylinders were used and they stroked together, but the principles of compounding met with little favor at that time and soon dropped out of use.

Roentgen, 1834.—However, Roentgen, a Dutch engineer, encouraged by the partial success of his predecessors and convinced of the correct thermodynamic principles of the theory of compounding, took out French and English patents in 1834 for a two-cylinder, compound engine applicable to the locomotive. This engine was to have the cranks set at 90°, thus overcoming the objections of the

* Superintendent, Baldwin Locomotive Works.

Woolfe type, and a receiver between the two cylinders, which was to be situated in the smokebox, thus allowing of some superheating before introducing the steam from the high-pressure cylinder into the low.

Craddock, 1846.—The next proposed application of the compound principle to the locomotive was furnished by an Englishman. The design appeared in "The Chemistry of the Steam Engine" by Thomas Craddock, and was patented in 1846. It was a four-cylinder compound with a high and low-pressure cylinder on each side and situated one above the other, the upper low-pressure cylinders inclined and the lower high-pressure ones nearly horizontal. Each was provided with a cross-head, and the two connecting rods on each side were coupled to the same crank pin. A condenser was another feature of this design.

Nicholson, 1850.—In 1850 James Nicholson, an engine driver on the Eastern Counties Railway of England, brought to the notice of the Locomotive Superintendent, Mr. James Samuel, a design for a two-cylinder compound, in which it was proposed to expand one-half of the high-pressure exhaust in a second cylinder, and to utilize the other half in creating sufficient draft, by allowing it to exhaust up the stack. Two years later two of these engines were built and a fuel saving of 20% claimed for them.

Kemp, 1860.—Mr. Ebenezer Kemp of Dundee, connected with the Glasgow and Southwestern Railway, invented a special arrangement of cylinders for working the steam on the Woolfe principle.

Morandiere, 1866.—The first three-cylinder compound to be suggested was brought forth in a design by Mr. Jules Morandiere of the Northern Railroad of France. This was for an eight-wheel engine coupled in two groups. The rear set was to be driven by a single high-pressure cylinder working on a crank axle, while the front set was to be operated by two low-pressure cylinders outside, provision being made for starting with boiler steam.

Hudson, Perry and Ketcham, 1867-68.—In 1867 Mr. Hudson of the Rogers Locomotive Works brought out a design for a two-cylinder locomotive, and, in the following year, a Hinkley engine was altered to a tandem compound for the Erie Railroad, after designs by H. O. Perry and Edward M. Ketcham. This was the first four-cylinder compound ever run.

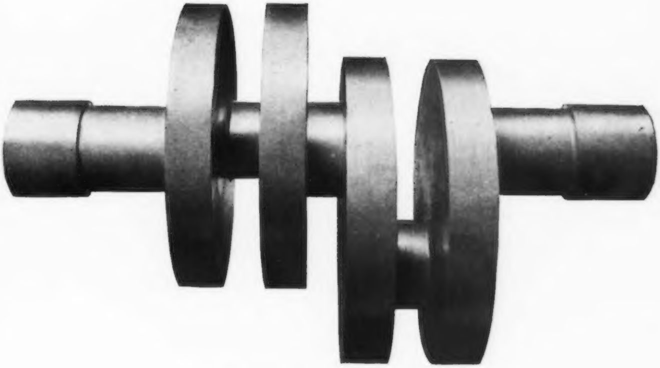


FIG. 1.—BUILT-UP CRANK AXLE.

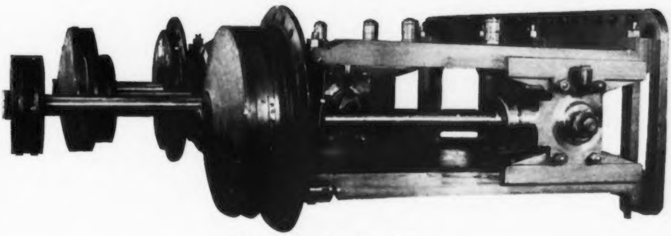


FIG. 2.—PISTON AND GUIDES.

Dawes, 1872.—Mr. William Dawes, of Kingston Grove, Leeds, England, proposed, in patent specifications dated 1872, to expand steam in two pairs of cylinders, the two high-pressure cylinders to connect to one axle, and the two low-pressure cylinders to the other, thus doing away with side rods. He also set forth another scheme by which all four cylinders were to be attached to one axle, the two high-pressure cylinders being connected inside to cranks, and the outside low-pressure cylinders to crank pins. Here, then, are the essentials of the balanced compound at a rather early date. In 1884 a locomotive was compounded for one of the Indian roads upon the principles laid down by Mr. Dawes.

Mallet, 1876.—In 1874 Mr. Anatole Mallet began his designs for a two-cylinder compound, and two engines were built and operated on the Bayonne and Biarritz Railroad in 1876. These engines proved to be a decided success and have been introduced into Germany, Russia, England, Spain and America and other countries with slight modifications. The Mallet type has the two cylinders outside connected, and a reducing valve which allows working the engine as a single-expansion with steam of reduced pressure in the large cylinder. Mr. Mallet also brought out designs for a four-cylinder tandem compound with the high-pressure cylinders fixed to the front covers of the low-pressure cylinders. He is also the originator of the articulated compound, in which the driving wheels are divided into two sets. The high-pressure cylinders are bolted to the middle of the boiler, and the cross-heads are coupled to the rear group of driving wheels. The forward group of driving wheels is arranged as a truck, to the frames of which the low-pressure cylinders are bolted, the steam exhausting from the high-pressure to the low-pressure through a ball-jointed pipe.

Webb, 1878.—Two years after Mallet's locomotives were built, F. W. Webb, Locomotive Superintendent of the London and Northwestern Railway, convinced of the results obtainable by compounding, altered one of his engines to the Mallet type.

Von Borries, 1880.—In 1880 Mr. August Von Borries, then engineer of the Prussian State Railways, introduced a simplified form of the Mallet compound on that road. This engine was provided with outside cylinders and an intercepting valve of the disc type, which allowed the engine to start single expansion, but permitted it to be thrown into compound.

Webb, 1881.—The next event in the history of the compound is the advent of the three-cylinder engine. The results obtained from the old Trevethick engine, which Webb altered to a Mallet compound, were so satisfactory that three years after, in 1881, he brought out the type which now bears his name. This engine was arranged with two high-pressure cylinders connected to the rear driver, and one low-pressure cylinder connected to a crank on the front axle. Two starting valves were provided, one allowing the high-pressure exhaust to enter through the stack, in case the low-pressure was on its center, and one admitting the high-pressure steam to the receiver when the low-pressure was not on its center.

Dunbar, 1883.—The next two steps in compound progress were further applications of types already built and tried. In 1883 H. D. Dunbar designed a tandem compound for the Boston and Albany Railroad, but this engine did not give satisfaction and was soon changed into a single expansion engine.

Worsdell, 1885.—Two years later, T. W. Worsdell, of the North Eastern Railway of England, introduced, on that road, a modification of the Mallet two-cylinder compound, which was decidedly successful. Worsdell put the two cylinders inside the frame and used a flap form of intercepting valve, which after starting as single expansion threw the engine automatically into compound.

De Glehn, 1885.—In 1885 A. G. de Glehn further developed the design introduced by Dawes ten years previously, and designed a balanced compound with two high-pressure cylinders connected outside to the crank pins of the rear wheels, and two low-pressure connected to cranks on the front axle. The original was to be without side rods, but so much difficulty was experienced in starting the engine that the rods were afterward put on.

The advantages claimed for this design were:

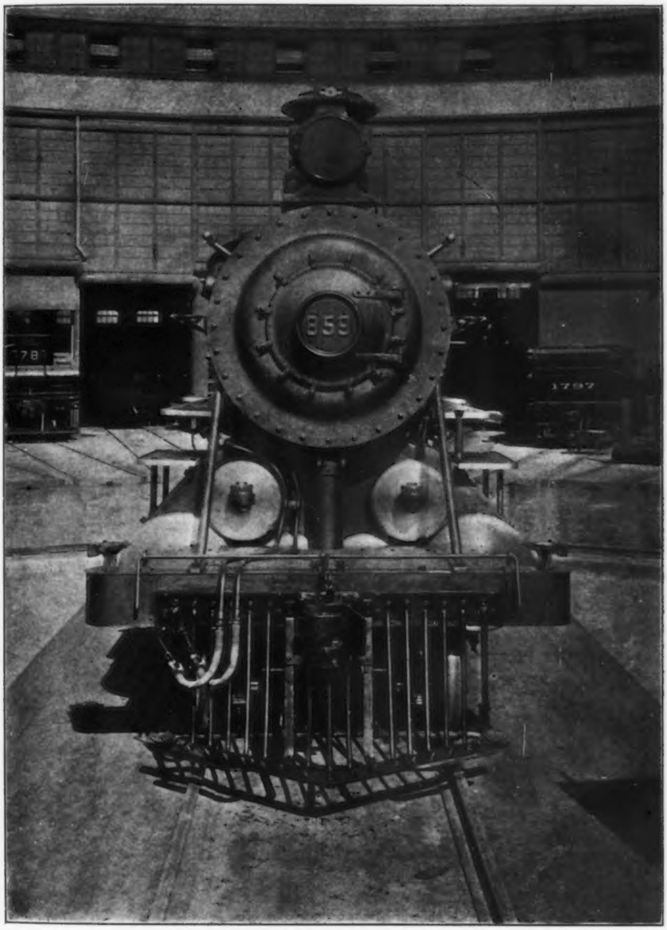
First.—That the steam was led more directly from the boiler to the stack than in other designs of compound locomotives;

Second.—That the four valves obviated the necessity of handling boiler and low-pressure exhaust steam with the same valve;

Third.—That the flat valves used had an advantage over the piston valves, in that they could be kept tight with greater ease;

Fourth.—By dividing the power between the two sets of drivers, the stresses were reduced.

PLATE XXII. VOL. LIV. PART D.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
VAUCLAIN ON
THE BALANCED COMPOUND LOCOMOTIVE.



FRONT VIEW OF VAUCLAIN BALANCED COMPOUND LOCOMOTIVE.

Woolfe, 1889.—About 1889 an engine was designed for the Northern Railway of France on the Woolfe principle. This was a tandem compound with low-pressure cylinders in front. The large piston was provided with two rods, one running above and one below the high-pressure cylinders, thus making one cross-head take three rods, and, at the same time, avoiding a gland between the two cylinders.

Vauclain, 1889.—In 1890 the Baldwin Locomotive Works brought out the first Vauclain four-cylinder compound, with the high and low-pressure cylinders superimposed on each side, their piston rods connecting to the same cross-head.

Johnstone, 1890.—During the same year, an engine was built after a design by Johnstone, somewhat similar in principle to the Woolfe compound, with three piston rods connected to one cross-head, the difference being that the high-pressure cylinder was placed within an annular low-pressure cylinder.

Du Bosquet, 1891, and Wright, 1891.—From this time, the story of the compound becomes rather intricate, in that many engineers turned their attention to the problem involved. In 1891 du Bosquet introduced a form of de Glehn compound with the same connections, except that the cranks on the rear and front drivers were 162° apart instead of 180°, to facilitate starting. This engine was tried without side rods, but did not give satisfaction unless coupled. In the same year, Wright got out an American patent for an engine to have two high-pressure cylinders outside connected, and two low-pressure cylinders situated under the smokebox and connected to the cross-heads of the high-pressure pair by a system of levers.

Vauclain, 1892.—In this year, the Baldwin Locomotive Works brought out an improved two-cylinder automatic compound from the designs of S. M. Vauclain.

Meyer-Lindner, 1892.—In 1892 an articulated, duplex compound was designed by Meyer and Lindner. It comprised two four-wheel trucks, the rear set of which was driven by two outside-connected, high-pressure cylinders, and the front set by the same arrangement of low-pressure cylinders. Both the high and low-pressure cylinders were situated in the center of the engine.

J. B. Smith, 1892.—In the same year, J. B. Smith designed an engine which was built by the Dunmore Iron and Steel Company for

the Erie and Wyoming Valley Railroad, which had three high-pressure cylinders set 120° apart on the front axle. Two were placed outside and one inside, close to one driving box, thus leaving all the eccentrics on one side of the crank.

Strong, 1896.—The next step in the United States was taken by Strong, who altered one of his original engines to the balanced compound type. The special feature of this engine lay in the effort of the designer to get the same weight of reciprocating parts in the high and low-pressure cylinders by making the pistons and rods of the latter hollow. The revolving parts were counterbalanced by weights added to the wheels opposite the pins, but close to the hubs. The high-pressure cylinders were placed inside the frames and the low outside, connecting to the same pair of drivers.

Von Borries, 1897.—The Von Borries design of balanced compound is rather different from the de Glehn type, in that the high-pressure cylinders are placed inside and connected to cranks on the axle of the drivers to which the low-pressure cylinders are externally connected. Two valves and one valve motion are used for each pair of cylinders. In the first engines built from these designs, the cranks were not exactly opposite, but in later designs, they were placed 180° apart.

Von Borries recognizes that when the side rods transmit their share of the piston thrusts to the rear drivers, the front axles are subjected to no greater strains than in the de Glehn type, and that the strains produced in the axles of the single-expansion inside-connected engines are never approximated.

W. J. Smith, 1898.—In 1898 an engine on the North Eastern Railway of England was compounded on the W. J. Smith system. It had two low-pressure cylinders, outside connected, 90° apart, and one high-pressure inside, connected to the same axle, bisecting the obtuse angle formed by the two outside pins.

Single-Expansion Balanced, 1900.—A form of balanced engine appeared in 1900. It had four high-pressure cylinders connected to the front driving axle, two inside, operated by one valve, two outside cylinders operated by a valve set on top of each. For this arrangement, two valve motions were necessary.

Webb, 1900.—In the same year, Webb brought out a four-cylinder balanced compound for the London and Northwestern Railway. It

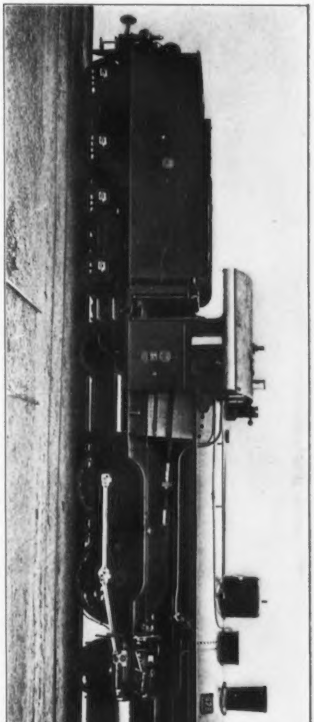


FIG. 1.—VON BORRIES BALANCED COMPOUND LOCOMOTIVE.

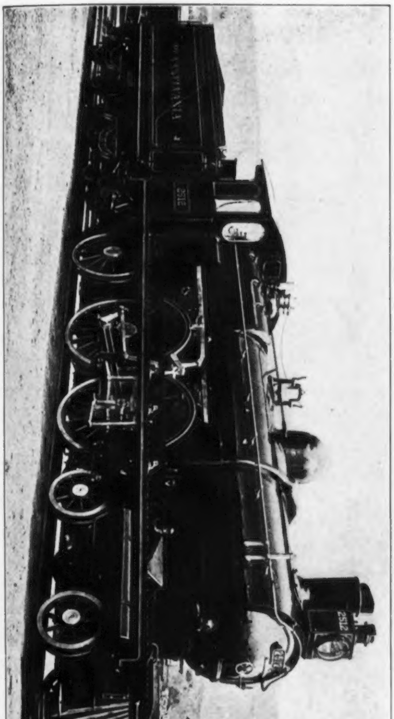


FIG. 2.—THE DE GLEHN BALANCED COMPOUND LOCOMOTIVE.

was an eight-wheel passenger with two high-pressure cylinders inside, and the two low-pressure cylinders outside, connected to the same axle. Four valves were still used, although they were driven by one valve motion as in the Von Borries.

In 1900 there were at least two foreign designs for six-coupled balanced compounds on the de Glehn system; that of Mr. Salomon of the Eastern of France, and that for the Bavarian State Railways built at the works of J. A. Maffei, in Munich.

Vauclain, 1902.—In 1902 the Baldwin Locomotive Works brought out the Vauclain balanced compound. This engine was built for the Plant System and had six-coupled wheels. The high-pressure cylinders were connected to the cranks on the forward axle, and the low-pressure cylinders to the crank pins on the forward wheels. Two piston valves served to distribute the steam to these cylinders and were operated by the customary valve motions.

The compound locomotives may be roughly classified by the countries with which they are most closely identified, as follows:

First.—The two-cylinder compound, Germany;

Second.—The three-cylinder compound, England;

Third.—The four-cylinder balanced compound, France;

Fourth.—The Vauclain four-cylinder compound and the tandem compound, America.

The various designs of four-cylinder compounds have been admirably classified by A. Herdner, as follows:

First.—Two main crank pins and two valve motions;

Second.—Four main crank pins and two valve motions;

Third.—Four main crank pins and four valve motions.

Class 1 comprises the Vauclain, Johnstone and tandem-compound type. No crank axles are used in this class.

Class 2 comprises such engines as the three engines exhibited at the Paris Exposition in 1900 by Messrs. Webb, Von Borries and the Meridional Railway of Italy, and the Vauclain balanced compound. The four cranks are on the same pair of wheels, a crank axle being used. The Italian engine has one valve motion for the two high-pressure cylinders and one for the two low-pressure cylinders.

Class 3 comprises the de Glehn, Mallet swivel truck and such engines as those built for the State roads of Saxony, the Paris,

Lyons and Mediterranean Railway, Saint Gothard Railway, and the Central of Switzerland. The four cranks are on two axles, a crank axle also being used.

The de Glehn and one of the Saxony engines have two reverse shafts operated independently. The Paris, Lyons and Mediterranean engines also have two reverse shafts, but they are independent. The Mallet type, the Saint Gothard engine and the Central of Switzerland have single reverse shafts.

At present, the balanced compound locomotive designed by the Baldwin Locomotive Works is the only design in actual service on American roads. In France, however, there are over a thousand such locomotives in operation, and they are meeting with great favor. These engines are of the de Glehn type, by whom they were developed in conjunction with such able engineers as du Bosquet, Solacroup, and Baudry. The remarkable performance of these engines has attracted the attention of progressive minds of other countries, and has invaded England, the mother of the art, as well as the stronghold of conservative railroad methods. The Pennsylvania Railroad has also imported an example of the French type of locomotive, shown in Fig. 1, Plate XXIII.

In this type, two low-pressure cylinders are cast in one piece, and are located between the frames, the piston being connected to the cranked axle of the forward pair of drivers. The high-pressure cylinders are bolted to the outside of the frame and are in the rear of the low-pressure cylinders, the piston of these cylinders being coupled to crank pins on the rear driving wheels. This arrangement of cylinders permits the use of rods of approximately the same size on both high and low-pressure cylinders, an essential condition for securing a perfect balance of the reciprocating parts. The saddle of the low-pressure cylinders forms a receiver, into which is exhausted the steam from the two high-pressure cylinders. Four separate D valves are used and are driven by separate valve motions of the Walschaert type, which are regulated by two reverse levers. With this type of engine, that is, those in which one cylinder is set ahead of the other, it is necessary to place the low-pressure cylinder between the frames so as to secure a direct exhaust to the stack.

Von Borries, the eminent German engineer, has recently brought out a design of balanced compound which has a cylinder arrangement similar to that designed by the Baldwin Locomotive Works.

PLATE XXIV. VOL. LIV. PART D.
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VAUCLAIN ON
THE BALANCED COMPOUND LOCOMOTIVE.

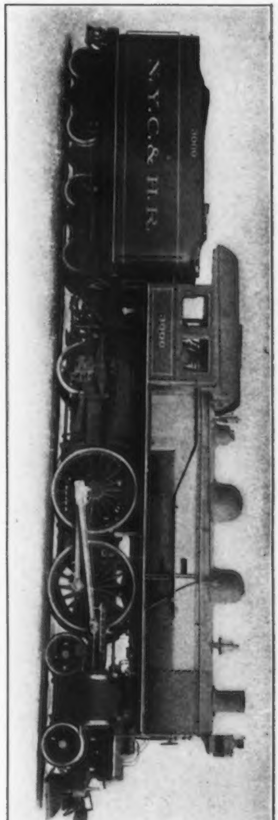


FIG. 1.—COLE FOUR-CYLINDER BALANCED COMPOUND PASSENGER LOCOMOTIVE.

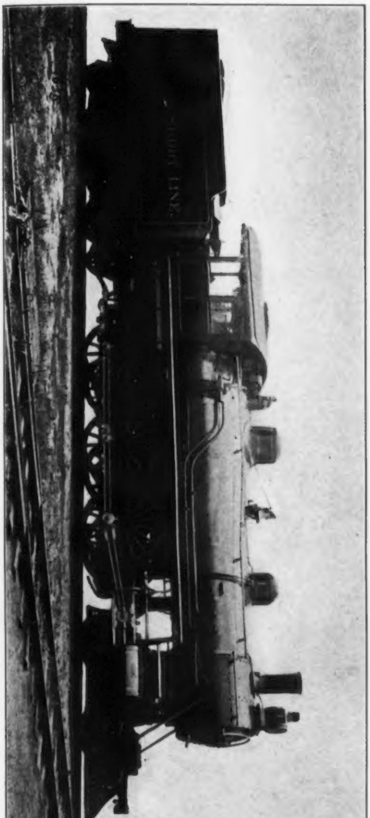


FIG. 2.—VAUCLAIN BALANCED COMPOUND LOCOMOTIVE.

This handsome engine is shown in Fig. 2, Plate XXIII. The four pistons are coupled to the same driving axle. The engine has four valves, the outside low-pressure being a D valve, and the inside high-pressure, piston valves. The Walschaert motion is used, but both high and low-pressure valves on one side are controlled by a single gearing. The Prussian State Railway has twenty-nine engines of this type in service, and their successful performance has induced the officials to place orders for nineteen more.

One of these engines, exhibited at the Louisiana Purchase Exposition, has been run over the Vandalia line; it maintained an average speed of 71 miles per hour, with a train of 200 tons behind the engine.

The American Locomotive Company has recently built one balanced compound for the New York Central and Hudson River Railroad. This engine has a high and low-pressure cylinder cast in one piece. The high-pressure is coupled to cranks on the front axle and is in advance of the low-pressure cylinder projecting from beneath the smokebox. The outside low-pressure cylinders are connected to crank pins on the rear driving wheels. A very long piston valve is used, the front end controlling the steam cycle of the high-pressure cylinder and the rear portion that of the low-pressure cylinder. By placing one cylinder in advance of the other, an approximate balance of the main rods is secured, even though the outside and inside cross-heads are coupled to different pairs of wheels.

The Baldwin balanced engine is the first successful balanced compound designed or built in America, and it is not too much to say that the original four-cylinder Vauclain compound has prepared the way for the adoption of this present type of locomotive, and the experience gained in the design of 3 000 of these engines proved to be of infinite value when the problem of the selection of the most satisfactory arrangements for the new type of engine arose.

The intricate steam ports, the long heavy valve, the inaccessibility of the guides and difficulty of placing them in alignment were factors which weighed against locating one cylinder in advance of the other, although such a design was actually made in order to study thoroughly the various features.

The cylinders of the balanced compound are essentially the same as in the original type of the Vauclain four-cylinder compound en-

gine, except that they are turned to an angle of 90°, thus greatly simplifying the casting. Instead of the cylinders being superimposed and located outside of the locomotive frames, they are placed horizontally, the low-pressure outside and the high-pressure cylinders inside of the frames.

General Dimensions of Baldwin Balanced Compound Locomotive, Class $10\frac{24}{44}$, D99.

Gauge	4 ft. 8½ in.;
Cylinders	15 and 25 by 26 in.;
Drivers	73 in.;
Total wheel base	29 ft. 2 in.;
Driving wheel base	14 ft. 1 in.;
Weight, total, about	176 510 lb.;
" on drivers, about	129 010 lb.;
Boiler, diameter	62 in. increased to 80⅜ in.;
Number of tubes	341;
Diameter of tubes	2 in.;
Length of tubes	15 ft. 0 in.;
Firebox, length	131 in.;
" width	59½ in.;
Heating surface, firebox	128 sq. ft.;
" " tubes	2 665 sq. ft.;
" " total	2 793 sq. ft.;
Tank capacity	7 000 gal.

The cylinders were designed with a view to securing a strong casting without any intricate ports or passages and to enable the use of a strong frame connection. Attention is particularly directed to this feature, the section shows that the live steam and exhaust passages are very direct; the simple lines and the strength of the casting are well illustrated. These are essential features for a successful high-powered locomotive. The axes of the four cylinders are parallel and in the same horizontal plane. The saddle is cast in two pieces, one high and low-pressure cylinder and one valve chamber being in each piece.

The slide valves are of the piston type and are located above and between the cylinders which they are to control. This valve is also a development of the original Vauclain valve.

FIG. 1.—CYLINDERS OF VAUCLAIN BALANCED COMPOUND LOCOMOTIVE.

FIG. 2.—VALVE OF VAUCLAIN BALANCED COMPOUND LOCOMOTIVE.

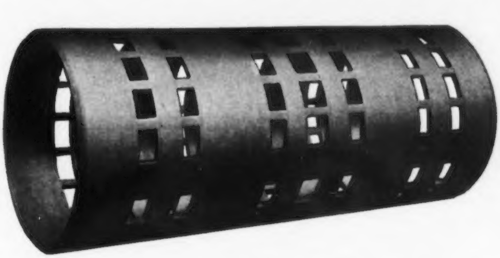


FIG. 3.—VALVE BUSHING OF VAUCLAIN BALANCED COMPOUND LOCOMOTIVE.

The live steam port is centrally located between the steam ports to the high-pressure cylinders, and is opened to connection with either one by the central cavity in the valve itself. The steam is exhausted through the other high-pressure port to the interior of the valve, the valve being open at both ends, forming a receiver of the entire valve chamber and securing a perfect balance to the valve.

The outer edge of the valve controls the admission of steam to the low-pressure cylinder. The high-pressure exhaust steam passes from the front of the high-pressure cylinder through the valve to

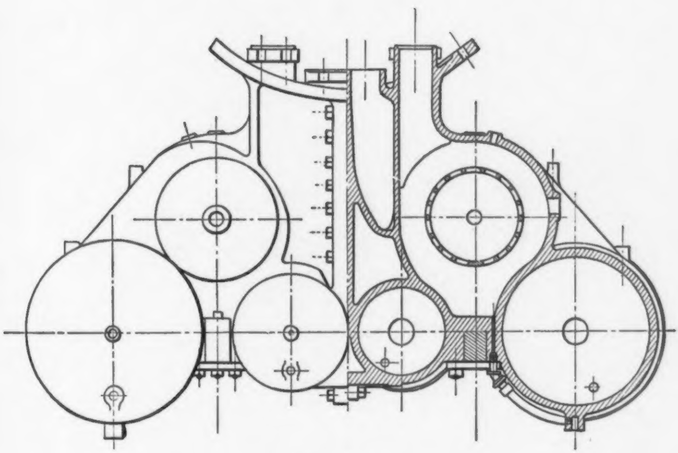


FIG. 43.

the front of the low-pressure cylinder, or from the back of the high-pressure cylinder to the back of the low-pressure cylinder. The exhaust from the low-pressure is governed by the two outside cavities of the valve in the same manner as in ordinary slide valves. The starting valve connects the two live steam ports of the high-pressure cylinder, allowing steam to pass over the high-pressure piston to the receiver, and thus directly to the low-pressure cylinder.

The valve motion is practically the same as in the single-expansion locomotive, a single set of valve gear controlling the steam

distribution, on one side of the engine, of the high and low-pressure cylinders.

The high-pressure cylinders inside are coupled to a crank axle with cranks set at 90°, and the left high-pressure crank is set at 180° to the outside left low-pressure crank pin; the high and low-pressure pistons are, therefore, traveling at the same moment, in

DIAGRAM OF THE
VAUCLAIN BALANCED COMPOUND CYLINDER
AND PISTON SLIDE VALVE

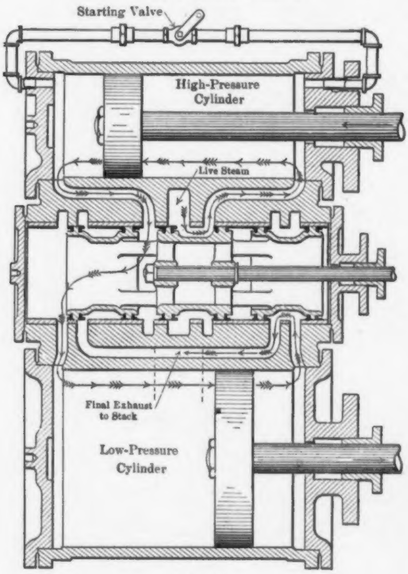


FIG. 44.

opposite directions, the reciprocating parts being balanced one against the other.

Various types of crank axles have been used. A type largely used in Europe is shown in Fig. 1, Plate XXVI. This has four webs and is forged from a solid steel ingot, the pins and connections between the two central webs being slotted and then turned. The

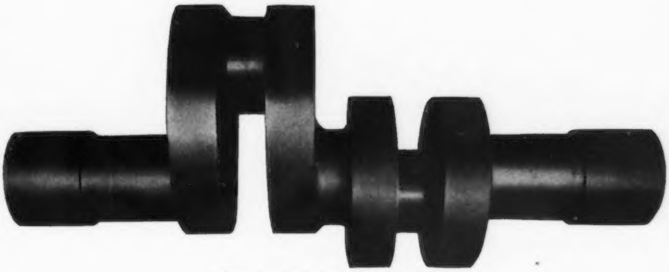


FIG. 1.—FORGED CRANK AXLE.

FIG. 2.—FORGED Z CRANK AXLE.

pins are drilled and bolted to secure them from falling on the track should they break, bands being shrunk on the webs for similar reasons.

A more recent type, largely used in France, and designed by Mr. Seimens, is known as the Z-shaped axle. This axle has but two webs, and is likewise forged from a solid ingot, but it is lighter in weight and enables the manufacturer to secure more hammered work upon the pins. It is, however, more difficult to balance perfectly than the other type of axle, and cannot be secured against breakage by bolts and bands.

These solid forged axles are very expensive to make, and while an investigation has shown that they will make between 300 000 and 400 000 miles before they may require renewal, there is no possible means of repairing them in the event of their failure. A built-up crank axle would, therefore, appear to offer many advantages. It permits the use of well-forged steel in the crank pins and webs, and they should never break in service. The only possible way in which such an axle may fail would be for the pins to work loose. This may be remedied at a small expense by boring out the web and replacing the pin, an insignificant expenditure when compared with the replacement of the forged axle.

Another type of this axle in which all the revolving parts are balanced in the same plane is shown in Fig. 2, Plate XXVII. In this design there is no bending moment, due to the whip of the cranks themselves, and no variation in pressure in the boxes from the same cause.

In all two-cylinder locomotives, whether single-expansion or compound, and in four-cylinder types, such as the tandem and the original Vauclain, the reciprocating parts are balanced by revolving weights in the driving wheels. A locomotive can be readily balanced to ride comfortably, but at high speed the excess balance weight acts, when down, with the dead weight on drivers, and against it when up, thus varying the pressure on the rail between very wide limits. This arrangement of balance becomes unsatisfactory for heavy locomotives and, particularly, when extremely high speeds are attained.

These counterweights, while partially balancing the reciprocating weights in a horizontal direction, throw themselves in an oppo-

site direction, and it is this vertical throw that plays such havoc with the track. The vertical throw of the excess balance can readily be calculated by the customary centrifugal formulas.

The diagrams (Fig. 45) show the magnitude of these forces varying from 0 to + 11 400 lb. and from 0 to — 11 400 lb. on each driving wheel in an ordinary two-cylinder single-expansion engine.

The first diagram in Fig. 45 is of a Baldwin four-cylinder balanced compound. This increasing and variable weight on the rails, caused by the excess balance weight in the driving wheels, has disappeared altogether, and, at all speeds, the greatest as well as the lowest, the weight on the rail is represented by a straight line.

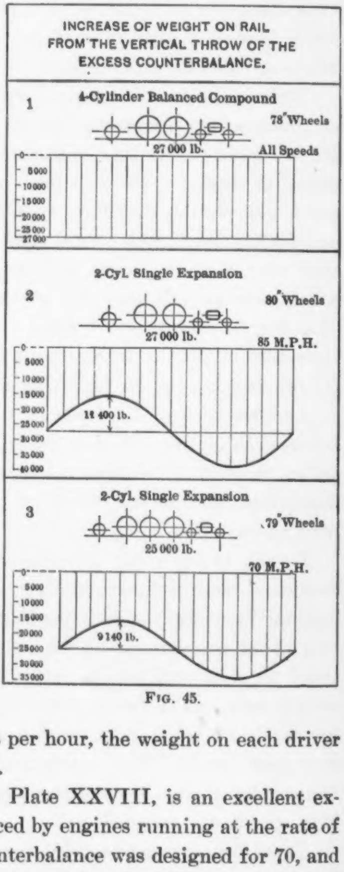


Fig. 45.

The second diagram (Fig. 45) is of a two-cylinder single expansion engine, with cylinders 20½ by 26 in., in use on one of the Eastern railroads. It shows that at 85 miles per hour, during 1 rev., the weight on each driver varies from 15 600 to 38 400 lb.

The third diagram (Fig. 45) is of a large two-cylinder single-expansion Pacific type engine, with cylinders 22 by 28 in. and in use on a Western railroad. At a speed of 70 miles per hour, the weight on each driver varies from 15 860 to 34 140 lb.

The piece of track, shown in Plate XXVIII, is an excellent example of the terrific strains induced by engines running at the rate of 104 miles per hour, when the counterbalance was designed for 70, and it offers the strongest possible argument for the balanced compound

PLATE XXVII. VOL. LIV. PART D.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
VAUCLAIN ON
THE BALANCED COMPOUND LOCOMOTIVE.

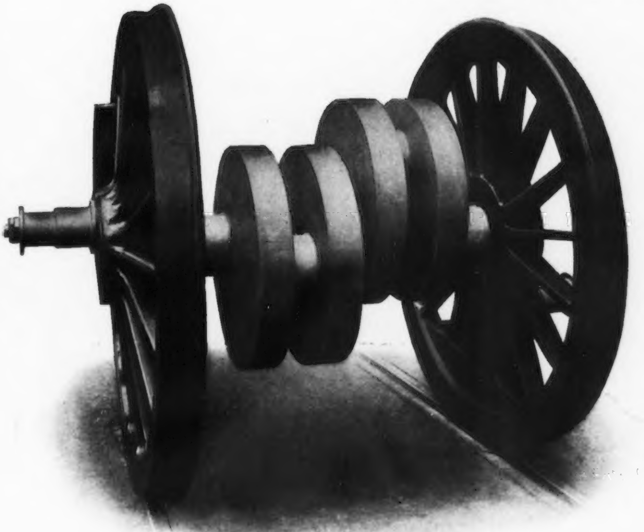


FIG. 1.—DRIVING WHEELS AND CRANK AXLE.

FIG. 2.—BALANCED AXLE.

RECORD OF RUNS OF
C. B. & Q. ENGINE NO. 2700.
JULY 3, TO AUG. 6, 1904.

Galesburg — Keewanee — Princeton — Mendota — Aurora — Chicago

Distance from Galesb'g: 32 Miles, 59 M., 80 Miles, 126 Miles, 163 M

July 3, 4, 5. Galesburg to Chicago.
Train No. 56 East, No. 55 West.
Had 1 & 2 extra cars and made extra stops. Made time easily.

July 7. Galesburg to Chicago.
Train No. 56 East, 12 cars. Regular number 9 cars.
Lost time made up ←7 minutes→←13 minutes→←7 minutes→
Made 9 stops and slowed down twice
Runs West No. 55, 5 to 6 cars, 4 hrs., 10 min. schedule time.

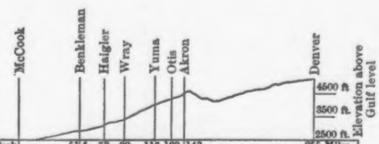
July 8. Galesburg to Chicago.
Train No. 56 East, 11 cars.
Lost time made up ←20 minutes→←19 minutes→←0→
Ran from Mendota to Aurora 46 miles in 46 minutes.
Between Aurora and Chicago made one extra stop and slowed down twice.

July 9. Galesburg to Chicago.
Train No. 56 East, 10 cars.
Running time from Galesburg,—34 Min.—58 Min.—78 Min.—123 Min.—176 Min.
Detentions—3 slows-1-stop

July 10, & 11. Burlington to Chicago.
Trains No. 6 & No. 7. Round trip 412 miles. No trouble to make time.
" No. 6, 6 cars, time 5 hrs., 5 min, with 9 stops.
" No. 7, 5 & 6 cars, time 4 hrs., 22 min. with 4 stops.

July 12, 13, 14. Burlington to Creston.
Train No. 13 & No. 12, 6 to 8 cars., Round trip 378 miles per day.
Engine used 6 tons less coal per round trip than P2., simple engines.

July 15. Creston to Chicago.
Morton special, 6 cars.
Distance 393 miles. Schedule 40 miles per hour.
Coal used, 10 tons.



Distance from McCook: 51.5, 73, 90, 117, 129, 143, 255 Miles
Profile McCook to Denver.

July 22. McCook to Akron.
Train No. 1, 7 cars.
Time from McCook. { Schedule—74 Minutes—216 Minutes. / Running—59— " —170 "
Four stops made, one of them 6 minutes. Coal used, 6 tons.

July 23. McCook to Denver.
Train No. 13, 7 cars.
Time from McCook. { Schedule—74—104—130—218 Minutes / Running—53—74—94—165 " On time.

July 24. Denver to McCook.
Denver to Akron 112 miles in 2 hrs., 30 min
Akron to McCook on time.

July 25. McCook to Akron.
Train No. 13, 6 cars, on time. Schedule 3 hrs., 38 min.
Returning No. 6, 8 cars, on time. Schedule 3 hrs., 10 min.

July 28. McCook to Akron.
Train No. 1, 8 cars including dynamometer car.
Time from McCook. { Schedule—74—129—173—216 Minutes / Running—68—118—154—186.5 "
Coal used 4½ tons, Max. Horse power 1050.

July 30. McCook to Denver.
Train No. 3, 10 cars.
Time from McCook. { Schedule—265 Minutes / Running—9 Minutes delay at Otis—215 " 3 Min. ahead.

Aug. 6. McCook to Denver.
Train No. 3, 11 cars. wet rail.
Time from Mc Cook { Schedule—81—149—265 Min. / Running—63—126—270 "
Made up 41 minutes Akron to U.P. crossing, made two stops and lost 16 min. from U.P. crossing to Denver, having run out of sand.

NOTE: In above runs the eastward schedule was slow and easily maintained.

FIG. 46.

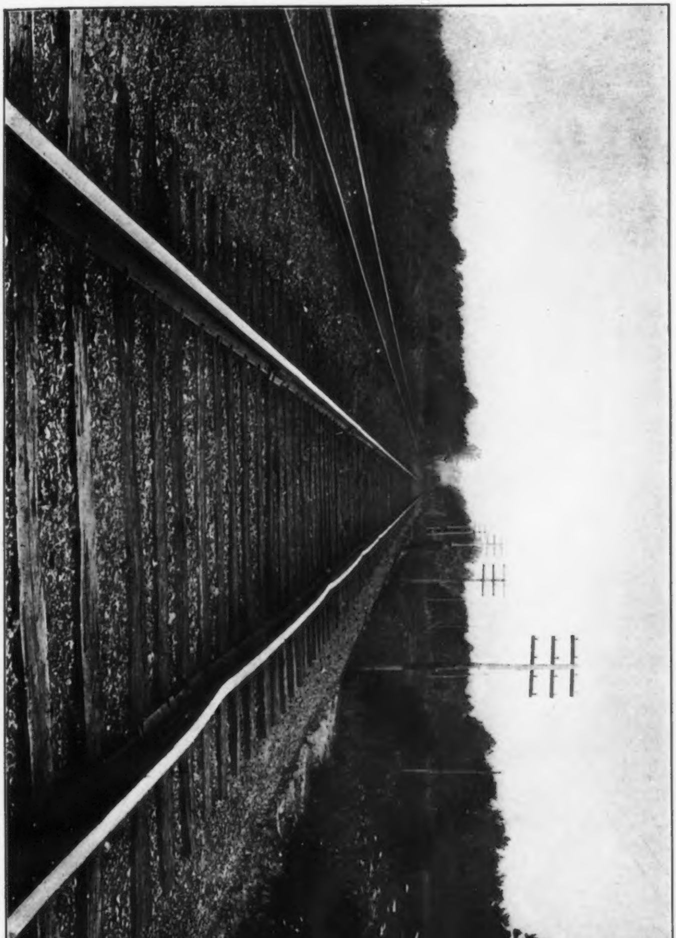
locomotive. By balancing the reciprocating parts against each other, the rotating balance in the wheels, customarily used to complement these parts, can be eliminated, in this manner avoiding the vertical shock and reducing the strain on the tracks to that directly due to the weight of the locomotive.

There are now forty-one balanced compound locomotives in actual service, and twenty-five more are in the course of construction. Wherever they are tried, the engines are meeting with great favor, and they are making phenomenal records for accelerating heavy trains to high speed and maintaining it. On the Atchison, Topeka and Santa Fé Railway, they successfully handle sixteen coaches between Topeka and Kansas City, and the following is an example of the average performance of these engines:

February 19th, 1904.

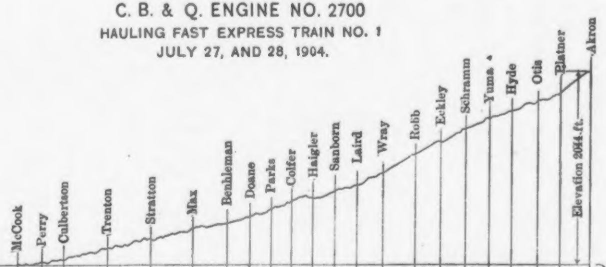
Train, Raymond-Whitcomb Special.
Dodge City to La Junta.
Distance, 202.4 miles.
Cars, 9 Pullman.
Weight of cars, 562 tons.
Time on road, 4 hours 26 min.
Delayed time, taking water, 14 min.
Actual running time, 4 hours 12 min.
Average speed, deducting stops, 48.2 miles.
Coal consumed, 8½ tons.
Water consumed, 14 600 gal. or 121 660 lb.
Water evaporated per pound coal, 7.15 lb.
Coal per 1 000 ton-miles, including weight of engine, 113.2 lb.
Grade from level to 34 ft. per mile.
Steam pressure regular, 220 lb.
Elevation, 1 450 ft. in 202.4 miles.
Weather, foggy; frosty rail for 50 miles; last 30 miles, heavy head wind.

The engine sustained an average speed of 48 miles per hour for more than 4 hours, while lifting a train of 560 tons, exclusive of engine and tender, to an elevation of 1 450 ft. A traveler riding in Pullman cars cannot realize the magnitude of this work, but a fireman (putting 2 tons of coal per hour in the firebox) knows that it means strict attention to business. In this run, the engine developed an average of 1 250 h. p. for 4 hours, and a maximum of about 1 600.



TRACK DISTURBED BY UNBALANCED LOCOMOTIVE.

RECORD OF TEST RUNS.
C. B. & Q. ENGINE NO. 2700
HAULING FAST EXPRESS TRAIN NO. 1
JULY 27, AND 28, 1904.



Between Stations	Miles between Stations	Maximum Grade Ft. per Mile
McCook–Perry	5.5	26
Perry–Culbertson	5.5	23
Culbertson–Trenton	10.4	29
Trenton–Stratton	11.7	26
Stratton–Max	9.8	34
Max–Benkleman	8.6	32
Benkleman–Doane	5.2	32
Doane–Parks	5.5	32
Parks–Colfer	5.1	34
Colfer–Haigler	5.5	32
Haigler–Sanborn	5.5	26
Sanborn–Laird	5.0	36
Laird–Wray	6.6	34
Wray–Robb	8.7	34
Robb–Eckley	6.1	34
Eckley–Schramm	6.3	34
Schramm–Yuma	6.3	32
Yuma–Hyde	5.6	32
Hyde–Otis	7.1	32
Otis–Platner	5.5	32
Platner–Akron	7.9	32

July 27, 1904

Station	Detentions	Schedule	Running Time	Registered Speed M.P.H.	Draw-Bar Pull, Lbs.	Horse-Power at Draw-Bar	Steam Pressure	Smoke-Box Temperature
McCook		A.M. 11.51	P.M. 12.05½					
Perry		P.M. 12.01		63	6000	1008	210	720
Culbertson		12.06		61	5500	894	203	750
Trenton		12.22	12.27	55	5200	703	210	
Stratton		12.40		55	4600	674	206	715
Max	Track Men	12.54	12.53	39½	6500	685	210	620
Benkleman	Air Hose	1.06	1.09 / 1.21					
Doane		1.15		52	6900	967	203	700
Parks		1.22		59	5200	818	206	706
Colfer		1.30		54	6100	878	207	706
Haigler		1.36		60	5200	832	207	740
Sanborn		1.44		54	6100	878	205	750
Laird		1.51		56	6500	971	200	750
Wray		2.03	2.08 / 2.13	56	6200	971		
Robb		2.17	2.25	49½	7250	967	202	760
Eckley		2.27	2.33	53½	6800	970	203	775
Schramm		2.36	2.40	53½	6000	927	205	750
Yuma		2.47	2.47 / 2.50					
Hyde		2.53	2.59	52	6800	943	203	750
Otis		3.03	3.09	55	6200	909	202	770
Platner		3.14	3.14	55	6000	880	196	775
Akron		3.30	3.24					

Elapsed Times (July 27)	Schedule	Running
McCook–Trenton	28 min.	21½ "
Trenton–Max	32 min.	26 "
Max–Benkleman	14 min.	16 "
Benkleman–Wray	55 min.	45 "
Wray–Robb	14 m.	12 "
Robb–Eckley	10 m.	8 "
Eckley–Schramm	9 m.	7 "
Schramm–Yuma	11 m.	7 "
Yuma–Hyde	8 m.	9 "
Hyde–Otis	10 m.	10 "
Otis–Platner	9 m.	5 "
Platner–Akron	16 m.	10 "

Train consisted of 10 cars including dynamometer car.
Total weight including engine and tender, 644 tons.
Coal used 8 tons.
Time Running 2 hr. 56½ min.
Average Speed 48.6 M.P.H.

July 28, 1904

Station	Detentions	Running Time	Registered Speed M.P.H.	Draw-Bar Pull, Lbs.	Horse-Power at Draw-Bar	Steam Pressure	Smoke-Box Temperature
McCook		A.M. 11.57					
Perry		P.M. 12.08	48	8000	1024	208	785
Culbertson		12.15	52	8000	1109	209	725
Trenton		12.27	50	8000	1067	205	
Stratton		12.41	52	8000	1109	196	
Max		12.53	50	7000	934	197	
Benkleman	Extra Stop for Water	1.03 / 1.11					
Doane		1.22	46	7700	945	197	730
Parks		1.29	51	6200	843		
Colfer		1.36	47	8300	1040	207	
Haigler		1.43	52	6500	900		
Sanborn		1.49	44	6200	728		
Laird		1.56	49	6200	810	186	
Wray		2.04 / 2.09					
Robb		2.24	42	7700	862	200	
Eckley		2.34	43	6100	700		
Schramm		2.44	38	6500	660	175	720
Yuma	Slowed down due to Coal and water getting low	2.53 / 2.55					
Hyde							
Otis		3.15	47	5600	702	195	
Platner		3.23	45	5200	625	180	
Akron		3.35					

Elapsed Times (July 28)	Schedule	Running
McCook–Perry	7 min.	11 "
Perry–Trenton	21 min.	19 "
Trenton–Stratton	18 min.	14 "
Stratton–Max	14 min.	42 "
Max–Benkleman	14 m.	10 "
Benkleman–Doane	7 m.	11 "
Doane–Parks	8 m.	7 "
Parks–Colfer	7 m.	7 "
Colfer–Haigler	8 m.	7 "
Haigler–Sanborn	6 m.	6 "
Sanborn–Laird	7 m.	7 "
Laird–Wray	12 m.	8 "
Wray–Robb	14 m.	15 "
Robb–Eckley	10 m.	10 "
Eckley–Schramm	9 m.	10 "
Schramm–Yuma	11 m.	9 "
Yuma–Otis	18 min.	20 "
Otis–Platner	9 m.	8 "
Platner–Akron	16 m.	12 "

Train consisted of 12 cars including dynamometer car.
Total weight including engine and tender, 719 tons.
Coal used 9 tons.
Time Running 3 hr. 23 min.
Average Speed 42.26 M.P.H.
" Draw-Bar Pull 7820 lb.
" Horse-Power 766
Evaporation 5.6 lb. water per lb. coal.

FIG. 47.

The Chicago, Burlington and Quincy Railroad has recently been putting one of these balanced compounds through an elaborate series of tests. This engine has inside cylinders coupled to the crank axle on the forward pair of drivers, but the outside cylinders are connected to crank pins on the rear drivers. Instead of locating one pair of cylinders ahead of the other, the piston rods on the outside cylinders have been lengthened, so as to secure main rods of approximately the same weights. This engine has been tried in all classes of service, being sent from one division to another. Some of these runs have been tabulated (Figs. 46 and 47), and the statements show that the engine has succeeded in making up time on the most severe sections of the respective divisions. It has also proved to be very economical in fuel, as compared with other engines, and the result of the trial has influenced the officials to place an order for nine additional engines of this type.

The compound engine has securely established its claim to economy, both of steam and coal, and those best qualified to judge believe that the compound can be as cheaply maintained as the single-expansion engine, or at least that the difference in the cost of repairs is not as great as the saving effected by the fuel economy. The four cylinders and crank axle are undoubtedly objections, which, however, are rather of a theoretical than of a practical nature, and any disadvantages from the duplicating of parts are far outweighed by relieving the running gear, the frames, and the track of the stresses due to the heavy reciprocating parts of the modern engine, and by the comfort which their perfect balance insures the hard-worked engineer and fireman.

Engineers are straining every nerve to meet this demand for increased capacity, and this type of four-cylinder balanced engine offers the greatest promise for future development in this direction.

FIG. 1.—VAUCLAIN BALANCED COMPOUND LOCOMOTIVE. ALL MAIN RODS COUPLED TO ONE DRIVER.

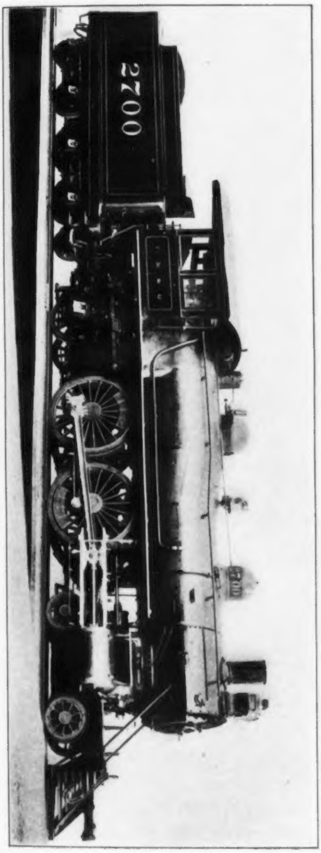


FIG. 2.—VAUCLAIN BALANCED COMPOUND LOCOMOTIVE. OUTSIDE AND INSIDE MAIN RODS COUPLED TO DIFFERENT DRIVERS.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS, 1904.

DISCUSSION ON LOCOMOTIVES AND OTHER ROLLING STOCK.

By Messrs. W. F. M. Goss, G. R. Henderson, A. Mallet, O. Busse, Karl P. Dahlström and Henry S. Haines.

W. F. M. Goss, Lafayette, Ind.* (By letter.)—The writer calls attention to Professor Forsyth's statement to the effect that the American type locomotive is no longer built for fast express service. With equal justice it might be said that the American type locomotive is no longer being built in the United States for any service, in view of which fact he believes that some tribute should be paid in recognition of its work and worth. Prof. Goss.

In the early days, it made little difference whether the service was freight or passenger, or whether the locomotive was for use on heavy grades or level track, the fitness of the American type was rarely questioned. As a response to early conditions, the type was almost perfect. Adherence thereto made the problems of the builder few and the cost of production low, and these were important factors at a time when track mileage was increasing at enormous bounds. As the same patterns were used over and over again, the form and proportions of every detail were proven in service upon hundreds of locomotives, hence the cost of maintenance was low. The type is well adapted to the rough track common in pioneer work, and is, moreover, very efficient as a steam power plant.

The decline of the American type is due to the fact that it cannot take on proportions which the modern locomotive must possess. Many different means were adopted in transforming the American

*Professor of Experimental Eng. and Dean of the Schools of Eng., Purdue University.

Prof. Goss. locomotive of 1876 into the American locomotive of 1893. The boiler was raised above the frames instead of extending between them, so that the firebox might be wider. The axle spacing of the drawing axles was increased that the grate might be made longer, and wheel-loads were augmented that the tractive power might be increased, but when all these measures had been carried to their limit, and more power was demanded, the abandonment of the type became imperative. It is not unlikely, therefore, that a machine which for forty years has been, in a remarkable degree, typical of American railway practice will soon disappear from the roads of this country.

G. R. HENDERSON, ESQ., New York City. (By letter.)—In Mr. Forsyth's paper there is no mention of the 2—6—2 or Prairie type of locomotive, although a large number are in satisfactory service on both Eastern and Western lines; this type should have been included in the list.

Regarding the safety of two and four-wheel trucks for locomotives, one of the large Western roads has, for years, operated passenger trains with locomotives having two-wheel trucks, and it is believed that it has full confidence in them. The two-wheel truck should not have to bear the odium of being unsafe, even by inference.

Regarding crank axles, the service of passenger engines in the United States is undoubtedly much more severe than abroad and the writer thinks it highly desirable to divide the cylinder work between two axles, especially with the crank axle and the large-sized cylinders which must now be used to obtain sufficient tractive force. The second design of compound, shown on page 268, would hardly admit of three pairs of drivers, as the main rods would be too short if six drivers were used with a trailer as in the Pacific type, which seems desirable for wide fireboxes and large driving wheels of over 100 000 lb. total adhesive weight.

The lubrication of valves is becoming more important daily, and the writer believes that current practice will soon fully indorse some type of forced-feed lubrication.

Mr. Mallet. A. MALLET, ESQ., Paris, France. (By letter.)—The writer has read M. Sauvage's paper with the utmost interest, and is very glad to see that his conclusions with regard to the application of the compound system to locomotives, as well as those of the heads of the locomotive departments of French railways, confirm the opinions presented by the writer in papers presented to the Société des Ingenieurs Civils de France in 1877 and to the Institution of Mechanical Engineers in 1879.

As to the construction with four cylinders, which is so generally used in France and which is the main subject of M. Sauvage's paper,

the writer asks permission to cite a portion of a paper by M. von Borries, the well-known German engineer and Professor, which paper is entitled, "The Development of the Compound Locomotive," and which was read before the Engineering Congress of Chicago in 1893.* Mr. Mallet.

"The arrangement of working one set of drivers by a pair of high-pressure cylinders and another set by a pair of low-pressure cylinders, these two sets of drivers being coupled or not, placed in the same rigid frame or in two articulated frames, was first mentioned in M. Mallet's *Mémoire* of 1877, page 958, and therefore these engines should be classed under the head of Mallet's system.

"The first locomotive of this type with rigid frame was an express engine built in 1885 by the Grafenshaden Works to the designs of M. de Glehn, engineer-in-chief for the Chemins de Fer du Nord (France), each pair of cylinders driving one pair of driving wheels which were not coupled together. More powerful engines of the same type have been built for the same road, and with similar general arrangement for the Paris, Lyons and Mediterranean Railway, in both cases with coupled drivers, etc."

The writer does not claim to have originated the principle of locomotives with more than two cylinders, rigid frame and two sets of uncoupled drivers as similar arrangements were proposed in 1866 by the late Jules Morandière, and patented in 1874 by Dawes, of Leeds, before they were carried out in 1881 by Mr. F. W. Webb and in 1885 by M. de Glehn, as has been stated above. The main object of the use of three or four cylinders by the said engineers was to do away with the coupling rods.

But the writer claims the credit of having been the first to propose the coupling of the axles in engines of that kind, and it is evident that it is that coupling of the axles which permits the most efficient realization of the aforesaid combination, because it gives a good balancing of the pistons and other pieces with reciprocating motion, by a suitable relative position of the cranks.

The writer desires to have it well understood that the above statements do not preclude, by any means, his regard and admiration for the engineers, to whom we are indebted for the high degree of perfection to which they have brought the locomotives which are the subjects of M. Sauvage's paper.

Mr. Busse. O. Busse, Esq., Copenhagen, Denmark.† (By letter.)—It is a well-known fact that tube-plates, in locomotive fireboxes and similar boilers, are stretched by the frequent rolling of the tubes.

If a tube-plate is fastened to the top-plate, which again is stayed to the outer shell of the boiler, the stretching of the tube-plate will cause a bending of the flanged part of the same, which, in time, will

* *Transactions*, Am. Soc. M. E., Vol. XIV, p. 1183.

† Locomotive Superintendent, Danish State Railways.

Mr. Busse lead to fracture. The stretching caused by the rolling of the tubes may amount to 30 mm. in locomotive boilers, before the firebox becomes otherwise defective and requires renewal.

Several constructions of stay-bolts have been introduced which allow the tube-plate to stretch, but these are only useful when there is no steam in the boiler. As soon as the steam pressure comes on, the top of the firebox will be pressed down just as far as the stretching by tube rolling had brought it up before, and the fracture of the flanged part will commence.

Much ignorance exists in relation to the expansion caused by heat. The writer made a stay-bolt, supplied with an extension which passed through a gland screwed into the socket and acting upon a lever with a proportion of 1 to 6, by which it was quite possible to measure the displacement of the firebox. Some few minutes after the fire was lighted the pointer showed 3 mm., answering to an extension of 0.5 mm., and afterward it rose steadily to 5 mm., where it remained until the steam began to rise. With a steam pressure of 1.5 atmospheres, the pointer still indicated 3 mm.—0.5 mm. extension—and fell back slowly to 1 mm., when the full pressure of 13 atmospheres was reached. After the boiler had cooled down, everything went back to the original state. From this it will be seen that, for the sake of extension caused by heat, it is not necessary to use flexible top-stays; it is only the extension caused by the rolling of the tubes which has to be made up.

The new arrangement which the writer proposes, and has introduced on the locomotives of the Danish State Railways, not only allows for the stretching of the tube-plate during the heating of the firebox, but also gives to the workmen the means of shortening the stays in proportion to the stretching of the tube-plate. Figs 48 to 52 show the different forms of stays which have been used hitherto.

Fig. 48 shows fixed stays by which it is intended to avoid the destruction of the firebox by placing the first row of stay-bolts as far away from the tube-plate as may be deemed secure, in order to make the angle of bending less.

Fig. 49 illustrates flexible stays, which allow the tube-plate to stretch during the heating of the firebox, but which do not prevent the top-plate from going back to its original state when the steam pressure is raised.

Fig. 50 shows the new form of stays, which are free to move and which allow the tube-plate to stretch, both during the heating of the firebox and when the tubes are being rolled; by this arrangement, also, it is possible to shorten the stay-bolts every time the tubes are being rolled; so that they will support the top-plate immediately when the steam pressure is coming on. The new arrangement ought to be used in the first row, or in the first and second rows, of stay-bolts.

The stay-bolts are to be screwed into the top-plate, and are free Mr. Busse. to move in a socket which is secured in the outer shell of the boiler. On this socket rests a nut by which the stay-bolt may be shortened each time the tubes are being rolled. Thus it is able to carry the top-plate, up as soon as the steam pressure is brought to bear upon it. To prevent the escape of steam, a capsule is screwed on top of the socket and tightness is secured by a washer of millboard.

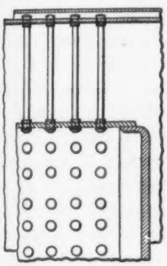


FIG. 48.

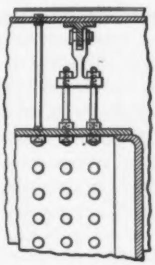


FIG. 49.

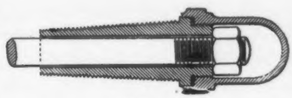


FIG. 51.

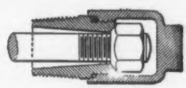


FIG. 52.

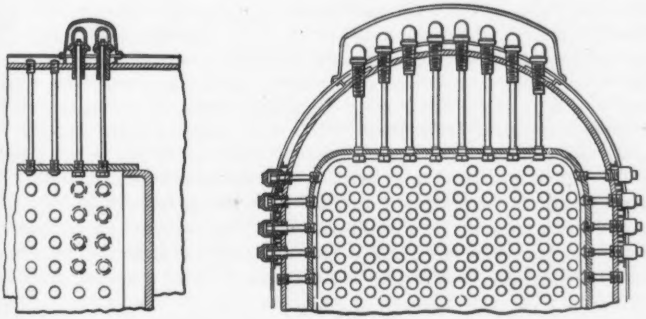


FIG. 50.

It has also been necessary to make up for stretching sideways in using this new form of stays, and this is easily done in the manner described above; but, in this case, the nut must be given a ball bearing, as shown in Fig. 52, to allow for the stretching of the fire-box plates up and down. As it is not always possible to get the side-stays at right angles to the plates, a hexagon head cannot be used, but, in such cases the stay-bolts must be riveted over after they are

Mr. Busse. screwed into the firebox plates, and, for this purpose, a long threaded nut is put on the outer end of the stay on which the holding on is done.

After this discussion was written the writer ascertained that the Paris, Lyons and Mediterranean Railway is using similar stay-bolts, but they are only applied to locomotive boilers with flat crown-sheets.

Mr. Dahlström. KARL P. DAHLSTRÖM, ESQ., Stockholm, Sweden.—The speaker has been connected for quite a number of years with the manufacture of locomotives, but, in that time, American practice has changed greatly, and he is not prepared to furnish any technical points of value. In regard to the matter of rolling stock, however, he would like to say a few words, from the point of view of the passenger, about the cars used in the United States. The speaker has spent many years in America, though now located in his native country, Sweden. Since leaving America, eleven years ago, he has tested the means of locomotion on railways in various European countries, and cannot refrain from saying that he considers the European practice, mentioned by M. Sauvage, as regards the arrangement of the carriages for night service, greatly to be preferred to the Pullman service which he has just had an opportunity to try once more on his passage from Washington to St. Louis.

Those present who have traveled in Europe are well acquainted with the style of carriage used there for the night service, *viz.*, a corridor passing along one side of the car or carriage and connecting with a series of compartments composing the sleeping rooms. These compartments sometimes contain four berths, sometimes two berths, and, in some cases, in the first-class service, only one berth—or there is only one berth used. With this arrangement of compartments a much more convenient plan of distributing the passengers in the car is obtained, and every passenger can have much more privacy and comfort without paying the high price demanded for a special compartment in a Pullman car. The car, during day service, of course does not contain the large salon common to all like the American car, but, in the compartments, there are comfortable places for those who wish to be together.

Passengers are not troubled much by the making up of beds. The speaker thinks that, in the Pullman car, the making up of beds requires, at least, four times as long as it does in a European car. It would interest him very much to know why, in the American practice—the Pullman practice, the present arrangement of the car is adhered to when there are such evident advantages in the arrangement referred to. Any one who has traveled in Sweden can give evidence as to the excellent quality of the cars for this service, which have been built there. The speaker believes that the Swedish cars far excel both the English and French and also the Ger-

man cars, in regard to the commodious arrangements for night traveling. He would like to know if this European style has been tried in America or why it would not be suitable in the American railway passenger service. He thinks that it would contribute greatly to the comfort of travelers in this country with its very great distances. He believes that as civilization, if he may use that word, extends more and more toward the Western border and in the degree that one can be sure of one's life in the cars, the majority of travelers would prefer to have that compartment style. The democratic idea of traveling all together in the same salon might have some weight, perhaps, in this country, but he maintains that from the standpoint of comfort the other arrangement is to be preferred. **Mr. Dahlström.**

HENRY S. HAINES, M. AM. SOC. C. E., Detroit, Mich.—The speaker is glad that Mr. Dahlström has provoked a discussion of this kind. The speaker has been general manager of a railroad for a generation and has witnessed the evolution of the sleeping car from the days when we used to lie doubled up like a jack-knife on a seat in a car. He has had built under his supervision a great many sleeping cars, and has recently supplemented his experience as a railway manager with some three years' traveling in Europe, and will endeavor to tell Mr. Dahlström of his experience. **Mr. Haines.**

There is not a mode of railroad travel on the Continent of Europe and in Great Britain that the speaker has not experienced. He has never had the pleasure, however, of being in Sweden, and therefore if his remarks seem to be somewhat in the nature of strictures on European methods, they do not apply to Sweden.

These methods are all developments, and the speaker may say that they were developed in America, because what Mr. Dahlström calls the European system of compartment or corridor sleeping car was devised in this country by what was known as the Mann Boudoir Sleeping Car Company. Mr. Mann was its originator; he took it to Europe, and it is Mr. Mann's car that persons who have traveled in Europe have had the opportunity of trying. The speaker has said these cars are a development, and they have developed from the fact that in the United States we put our cars on pivoted trucks instead of a rigid wheel base, and are enabled, therefore, to have longer cars with a thoroughfare through them, and are not liable to be forced to have unpleasant companions in that secluded cell which is known as the Mann boudoir. If a person wants the compartment to himself and wants to be exclusive or to travel with his own family only, for example, it is a very nice thing to have a private compartment. The Pullman system furnishes this to any one who will pay for it; but if one is alone—and one would rather be alone in a crowd than to be alone with a thief—the open sleeping

Mr. Haines. car is much preferred, at least in America. Another thing is that one has not that use of the seat, in the berth, as one has in a Pullman car. One can sit up or lie down, it does not make any difference about that if one rides in a Pullman, but if there is any one else in the compartment it makes a great deal of difference.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS, 1904.

ELECTRICAL POWER—GENERATING STATIONS AND TRANSMISSION.

Congress Paper No. 55.

By L. B. Stillwell, M. Am. Soc. C. E.,
New York City, U. S. A.

Discussion on the Subject by

G. Puente, Buenos Aires, Argentine Republic.
Z. T. Daniel, Iola, Kans., U. S. A.
N. A. Eckart, San Francisco, Cal., U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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1904.

Paper No. 55.

ELECTRICAL POWER—GENERATING STATIONS AND TRANSMISSION.

By L. B. Stillwell, M. Am. Soc. C. E.

A review of progress in the art of generating and distributing energy by electricity involves, on the one hand, consideration of improvement in specific apparatus and, on the other, a view of the evolution of systems, *i. e.*, of aggregations of apparatus. Within the limits of this paper it is possible only to refer briefly to some of the more conspicuous features of the development of a complex art which, during the last decade, has engaged the best efforts of many of our most brilliant inventors, scientists and engineers, and in attempting to sketch this development, a brief restatement of certain fundamental and well-known facts may be of use in establishing proper proportion and perspective.

The Development of Systems.

In the generation of electric power, mechanical energy, delivered by the steam engine, steam turbine, hydraulic turbine, or other prime mover to the shaft of the revolving element of the dynamo, is used to produce electricity in the armature of the dynamo, and in all dynamos used for power, or lighting purposes, this electricity is produced in the armature as an alternating current. In dynamos classed as continuous or direct-current machines, this alternating current

is rectified, *i. e.*, made unidirectional by a commutator attached to the armature of the dynamo and suitably connected to its windings. In those dynamos classed as alternators, a ring collector, comprising insulated rings of conducting metal, equal in number to the number of phases generated—or to some multiple thereof—is attached to the armature of the dynamos, and through this the alternating current, generated in the armature windings, is conveyed to circuits external to the machine. The comparative simplicity of construction of the ring collector as compared with the commutator is well understood, as is also the fact that an alternator can be wound conveniently and effectively to develop potentials greatly exceeding the limits considered practicable in the construction of continuous-current dynamos. As compared with the continuous-current dynamo, therefore, the alternator possesses, primarily, two marked advantages, *viz.*, (1) the simple and relatively cheap collector in place of the complicated and necessarily more expensive commutator; and (2) the ability to develop and deliver, to external circuits, a materially higher potential in cases where this is desirable.

In the case of the continuous or direct-current dynamo, distribution of electric energy involves essentially but two elements, *viz.*, switch-gear and conductors.

In the case of alternators, distribution is effected by two methods. The first applies to cases where the motors, lamps, or other translating devices can be operated by alternating currents. In this case, as in the case of continuous current, the essential apparatus required for distribution comprises only switch-gear and conductors. It is usual, however, to use transformers at one or both ends of the transmitting conductors in order that a potential higher than is otherwise practicable may be used in the transmission, and the cost of conductors thereby reduced. In the other case where alternators are used to generate the current, *viz.*, that in which the translating devices require continuous current for their operation, distribution involves the following apparatus: (1) switch-gear at power-house; (2) conductors for alternating currents; (3) alternating-current switch-gear in sub-stations; (4) transformers; (5) converters; (6) direct-current switch-gear in sub-stations; (7) direct-current distributing conductors. In this case also, transformers are frequently used at the power-house end of the line as well as in the sub-stations.

Generally speaking, in electro-mechanics, as elsewhere, the simplest organization of apparatus—that which involves the least number of links in the chain connecting cause and effect— is the best. Almost invariably it is the cheapest, the most reliable and the most efficient. In observing the progress of an advancing art, one cannot go far astray if this test is applied.

The simplest organization of electric apparatus for generating and transmitting power and utilizing it in mechanical form obviously comprises only a dynamo, a transmitting circuit and a motor. If but one dynamo and one motor be used, the switch-gear at both ends of the line may be very simple. If several dynamos be used for the generating plant, the organization of switch-gear at that end of the line necessarily becomes more complicated, and similarly an increase in the number of motors implies increased complication of switch-gear at the receiving end of the transmitting circuits. In large plants, the switch-gear becomes a very important element in the organization of apparatus.

Twenty years of work have made the commutator a thoroughly effective and reliable device, and to-day continuous-current apparatus would be capable of meeting every essential requirement in the development and transmission of electric power but for the fact that it appears impracticable to construct, for machines of constant electromotive force and large output, commutators for high potentials, the limit generally accepted to-day being about 750 volts, and the further fact that in distributing power for lighting and other purposes in residences, and even in mills and factories, considerations of safety to users and their property generally limit the potential used to something under 300 volts, the commercial limit commonly accepted approximating 220 volts, although some recent plants in the United States and in England use a potential of 440 volts.

Alternators, to-day, are frequently wound for potentials as high as 11 000 volts, and in some cases machines developing 20 000 volts are in successful operation. It is obvious, therefore, that the alternating system possesses immense advantage in respect to economy of transmission even without the use of the transformer at the generating station, while the use of the transformer at the receiving end of the transmitting circuits, operating at efficiencies frequently exceeding 98%, affords the ideal solution of the problem of high

potential transmission in connection with low potential distribution to users of power.

The development of electric apparatus during the last decade naturally has been directed primarily by the search for economy. The history of its progress is a record of successive attempts to attain given results at less, and still less, cost. Ten years ago the inherent limitations of continuous-current distribution were making themselves strongly felt. They had been appreciated many years before that time in a theoretical way, but it is, perhaps, not more than ten years since the companies operating electric lighting and power plants in our cities began to realize fully that a potential exceeding 220 volts was a commercial necessity. That within the last decade this necessity has been recognized, is demonstrated by the relatively marked increase in the use of alternating-current apparatus since 1894, a fact which stands out as the most prominent feature of the development of applied electricity during the last ten years. United States Census Bulletin, No. 5, issued about the end of 1903, shows in a striking manner the predominance of alternating-current plant equipment as existing in 1902. The following statistics are from Table 1 of the Bulletin referred to:

"Generating plant equipment:	
Dynamos—	
Direct current, constant voltage—	
Number	3 823
Horse-power	442 446
Direct current, constant amperage—	
Number	3 539
Horse-power	195 531
Alternating and polyphase current—	
Number	5 122
Horse-power	987 003
Output of stations:	
Kilowatt hours, total for year	2 453 502 652
Total number of arc lamps	385 698
Total number of incandescent lamps	18 194 044"

It will be observed that the rated output of alternators constitutes more than 60% of the total rated output of dynamos installed in central stations, which supply power exclusively for lighting and for general power purposes.

In the field of traction, the practical use of electricity began with the use of continuous-current apparatus. Continuous-current generators, 550-volt distribution and series-wound motors were used, and up to the present time, general practice has not been modified materially in respect to type or potential of the motors.

In the generation and transmission of the power supply, however, considerations of economy in production and distribution and of the importance of centralization of control have led, in a number of instances, to the adoption of a relatively complicated organization of apparatus, comprising alternating-current generation at high potential, transmission at this potential to a number of auxiliary or sub-stations, transformation to lower potential and conversion from alternating current to continuous current by transformers and converters located at these points, and distribution of the converted current to the moving car equipment by trolley conductors or contact rail. It is clear that such an organization of apparatus is not ideal. It is far too complicated. Nevertheless, when properly designed, constructed and installed, it is effective and efficient, as is demonstrated by the operation of such plants as those of the Interborough Rapid Transit Company and the New York Street Railway Company in New York City; the plant of the Niagara Falls Power Company, utilizing a part of its output to operate the street railway system in Buffalo and the interurban systems between Buffalo, Niagara Falls and Lockport; the plant of the Aurora, Elgin and Chicago Railway Company, and many other installations operating urban and interurban traction service.

In like manner, a number of the largest plants installed for lighting and power purposes in cities of the United States have, within the latter part of the decade just past, adopted the plan of transmission by alternating currents from one or more central stations and conversion to continuous currents at sub-stations, from which the continuous-current distributing network is supplied. In plants of this kind, transmission from dynamo to motor is effected, as has been stated, through a chain of connection having seven links, *viz.*, switch-gear in the power-house; alternating-current transmitting conductors; alternating-current switch-gear in sub-stations; transformers; converters; direct-current switch-gear in sub-stations and direct-current distributing conductors. Were alternating-current motors equivalent to continuous-current motors available, the converters and by far the

larger part of the switch-gear in sub-stations could be eliminated, attendants at the sub-stations would be radically reduced in number, or altogether dispensed with, and the sub-station buildings would be reduced to about 10% of their present cost. The efficiency of the system from dynamo to motor under full load would be increased from 3 to 10%, depending upon the size of the converter unit displaced, and the operation of the system, as a whole, would be greatly simplified and its reliability increased.

In America, it has been assumed generally that a motor suitable for traction service must be capable of operating efficiently through a considerable range of speed without external resistance, and until within the last two or three years efforts to produce an alternating-current motor satisfactorily meeting this requirement had not succeeded. Within the time named, however, two single-phase alternating-current motors, operating at speeds depending upon the potential delivered to their terminals, have appeared in America, and two in Europe, each of which may be regarded as successful though none has yet been tried commercially upon an extensive scale. These motors are now attracting wide-spread attention by reason of the great possibilities which they present, particularly in the field of traction. These possibilities rest not upon characteristics of the motor itself but upon the simplicity and economy of alternating-current transmission of power as compared with the composite alternating-current continuous-current system necessitated hitherto by the general selection of continuous-current traction motors.

It should be noted that even when the alternating-current motor is used as a traction motor, two different organizations of the transmitting apparatus are possible, one using no transformer between the trolley circuits and the circuits conveying energy from the power-house, while the other uses lower potential on the trolley circuits than is delivered to transmitting circuits from the power-house, and accomplishes the necessary reduction by using transformers located along the line of the railway. In the recent high-speed trials at Zossen, the former system was used, the potential from power-house and on the trolley circuits approximating 12 000 volts. One of the electric locomotives with which experimental runs were made, carried step-down transformers to reduce the trolley potential to a voltage more suitable for motor operation, while another locomotive which was tried, used no step-down transformers, its motors

being wound for 12 000 volts. Results have not been disclosed in sufficient detail to justify formation of an opinion of the relative advantages of the two equipments. The Ganz system, as used on the Valtellina Line in Italy, uses transformers located along the line to reduce the potential transmitted from the power-house—in this case 20 000 volts—to the potential used on the trolley circuits, *viz.*, 3 000 volts. The Ganz system uses no transformer upon its locomotives and motor cars, the traction motors being wound for potentials of 3 000 volts. Both at Zossen and on the Valtellina Line, tri-phase systems and tri-phase motors are used.

The new single-phase motors are wound necessarily for potentials even lower than the standard 500 volts used by continuous-current traction motors (some of those constructed thus far, are wound for 200 volts, others for 250 volts), consequently the use of step-down transformers on the locomotive or car, in sub-stations along the line, or in both, are necessary.

As regards transmission for operation of railways equipped with electric rolling-stock, particularly railways comparable in length and in general operating conditions with the steam railways of to-day, the substitution of the alternating-current motor for the continuous-current motor secures great advantage in respect to the simplicity and reliability of the transmission system, its cost and also its ability to provide adequately for congestion of traffic.

Its comparative simplicity is evident when it is considered that, as compared with transmission for operation of continuous-current motors, it eliminates the converters, and substitutes for the elaborate and expensive alternating-current switch-gear and continuous-current switch-gear in sub-stations the very simple switching and safety devices required by transformers.

The gain in respect to reliability, which results from the elimination of this apparatus, is materially greater even than the gain in simplicity and reduction of cost, by reason of the fact that the rotary converters in sub-stations, being necessarily operated in synchronism with the generators, are liable to fall out of step in case of short-circuits on the lines, and require appreciable time for synchronizing and the restoration of normal conditions.

The saving in cost will, in the largest plants, amount to not less than $25 per kw., and in smaller plants, it will be materially greater.

The substitution of a trolley potential of not less than 2 000 volts

for the normal, continuous-current trolley potential of 550 volts, which becomes possible by adopting the alternating-current motor, practically avoids the difficulty which the converter system of supply encounters in dealing with conditions of congested traffic. In the case of the converter system, such congestion as frequently occurs in railway traffic implies load upon adjacent sub-stations, which in extreme cases may amount to several times the normal load upon these stations, and provision for such congestion involves, therefore, the installation of sub-station apparatus and of distributing circuits to and from the sub-stations greatly in excess of the apparatus required for conditions of normal operation. The use of alternating-current distribution at 2 000 volts (or more) from the transformer sub-stations provides naturally and automatically for temporary concentration of the power supply normally distributed over a considerable section of the line.

Should experience demonstrate that it is practicable to use in regular operation trolley potentials as high as 12 000 volts, which was the potential used in the trials at Zossen, a railway of some length, *e. g.*, 30 or 40 miles, could be supplied economically without the use of either step-up transformers at the power-house or step-down transformers along the line, the only transformers required being those carried upon the locomotive or motor car and used for the purpose of reducing the trolley voltage to a potential suitable for motor operation, and it is even possible that these transformers also may be dispensed with. On the other hand, if the simple, efficient and comparatively cheap transformer be used in power-house and sub-stations, there appears to be no reason in general why 50 000 or 60 000 volts should not be used in the transmission circuits, and the adoption of a higher transmitting potential implies at least corresponding increase in the economical radius of transmission, and, therefore, in the length of track that can be supplied with power from a single generating station. It is not transcending the limits of conservative engineering statements to say, that to-day the art of generating and transmitting electricity and the art of utilizing energy thus transmitted for traction purposes are such that sections of trunk-line railways, 300 miles in length, can be supplied economically, and operated from a single power-house located midway between the ends of the section.

As regards development of the single-phase, alternating-current

motor, the Allgemeine Elektricitäts-Gesellschaft of Berlin for nearly a year has operated, upon the Spindlersfelde Line, a motor car equipped with motors of this type and weighing, without passengers, 56 tons. The length of the line is two and one-half miles. In operation, the motors are said to have proved thoroughly satisfactory, but at the time of writing this paper full disclosure of the results has not been made.

At Milan, Dr. Finzi has produced a single-phase motor which is said to have attained excellent results under test.

In America, the Lamme single-phase motor has been undergoing track tests for nearly two years near Pittsburg, and a single-phase motor developed by the engineers of the General Electric Company has been similarly tested with apparent success at Schenectady. The writer is informed that contracts have been closed by American companies for the equipment of not less than seven interurban railways using single-phase motors.

While the advantages of the single-phase, variable speed motor for traction purposes are obvious, American engineers, and designers in general, have apparently failed to realize, and they have obviously failed to develop in practical form, the possibilities of the tri-phase motor in traction work as those possibilities have been realized and developed by Ganz and Company, upon the initiative and under the able direction of DeKando. By far the most extensive and efficient alternating-current traction installation in operation to-day is the tri-phase alternating-current equipment installed by Ganz and Company, and operated for the last three years on the Valtellina Line between Lecco and Sandrio. The length of this line is 66 miles. It operates through a difficult country having many grades, some of which exceed 2 per cent. It has many curves. There is considerable snow in winter, and a very large proportion of the line being located at the foot, or along the slopes of steep hills, it is difficult to keep the tracks clear, and, in general, conditions of operation are such as constitute a fairly severe test of any traction system. The road handles a passenger and freight traffic of something over 200 000 ton-miles per day. Power is supplied by alternating-current transmission at 20 000 volts from dynamos driven by water-power, the potential of the transmitted energy being reduced to 3 000 volts by transformers located in substations or kiosks placed at intervals of approximately six miles along the line. The potential used upon the trolley circuits is 3 000

volts. The system being three-phase, two trolley wires are used, and the track forms the third conductor of the circuit. The frequency adopted is 15 cycles per sec. That the system is successful is sufficiently demonstrated by the fact that the Rete Adriatica, the company which operates all the Government railways in the eastern part of Italy, in July, 1904, accepted the complete installation, taking it off the hands of the contracting company which had installed it, several months before the expiration of the time during which, under the contract, the contracting company was to operate the equipment in order to demonstrate its success or failure.

Output and Size of Dynamos.—In considering changes which have occurred in respect to output and dimensions of dynamos, it is interesting to note, (1) the increase in output and consequently in dimensions of given types, such increase resulting directly from the demand for larger power units; and (2) increase of ratio of output to dimensions, as affected by speed of the prime-mover, and method of mechanical connection of the rotating element of the dynamo thereto, and by improved ventilation. The increase in dimensions, and still more in ratio of output to dimensions, during the last ten years has been marked. At the time of the Chicago Exposition, less than eleven years ago, the largest alternator constructed in the United States was rated 750 kw., and the practical limit of its output did not greatly exceed its nominal rating. It was a belt-driven machine with revolving armature, the speed being 150 rev. per min., and the frequency 60 cycles per sec. A so-called 1 500-kw., continuous-current, railway generator direct-connected to a vertical compound engine was shown, but the machine to-day would not be rated 1 500 kw. In Berlin, several 750-kw., continuous-current dynamos, direct-driven by vertical engines, were in operation (Ganz of Buda-Pesth had constructed a few alternators of about the same rating) and up to that time, the writer thinks nothing of greater output had been produced upon the Continent.

In England, at the Deptford Station, Ferranti had constructed one or two machines rated 1 250 h. p. (935 kw.) and had designed one of 7 500 kw., which was subsequently constructed but never operated commercially. The smaller machines were belt-driven. The large one was direct-connected to its engine.

Following these machines, the first noteworthy increase in output brings one to the Niagara generators, which were designed in

1893-94, and began commercial operation in the autumn of 1895. Up to the present time sixteen machines of the original Niagara type and five of the internal revolving field type have been installed by the Niagara Falls Power Company. The output of each of these machines is 3 750 kw. There are now under construction for the same company six machines, each of which is rated 7 500 kw. The most powerful steam-driven dynamos, thus far installed, are the 5 000-kw. alternators used by the Interborough Rapid Transit Company at its power-houses in New York City. These dynamos are capable of delivering 7 500 kw. for two hours with rise of temperature not exceeding 55° cent. The largest continuous-current dynamos hitherto constructed in America are rated 2 700 kw.

The march of progress in its effect upon ratio of output of dynamos to their dimensions has been particularly interesting. If the heat, due to internal losses, were dissipated perfectly, doubling the speed of a dynamo would mean, in general, doubling its output and although this relation does not hold, it remains true that dimensions and weight are vitally dependent upon speed. Owing to this well-known fact, the earlier dynamos were almost universally belted to the engines used to drive them, and in order to permit very high speed in a dynamo in conjunction with moderate or slow speed in the engine, it was not unusual to use countershafts in order to increase the ratio of speed from engine to dynamo. Loss of efficiency and waste of space implied by the use of belts led manufacturers, more than ten years ago, to begin the construction of the so-called direct-connected unit, *i. e.,* a unit in which the prime-mover and the dynamo operate at the same speed, the revolving element of the latter being usually mounted directly upon the shaft of the former; and at the present time it is safe to say that the belt, as a means of mechanical connection between engine and dynamo, is eliminated except in connection with comparatively small units, *e. g.,* 100 kw. or less.

This change from belted connection to direct connection involved a very material increase in the dimensions and weight of dynamos of given output. Some increase in cost per unit of output also resulted, but this has been offset in large degree, if not entirely, by reduction in cost due to reduction in cost of constituent material and to improvements in manufacture.

Following the general adoption of the direct-connected unit,

or more accurately, perhaps, coincident with this gradual adoption, the steam turbine has been undergoing development and within the last two or three years, a strong tendency to increase the speed of alternators has resulted from its rapid introduction as a substitute for the reciprocating engine. The marked effect of the increase in dynamo speed upon the ratio of its output to its weight is strikingly shown in Table 1, for which the writer is indebted to the Westinghouse Electric and Manufacturing Company. These dynamos are designed for direct connection to steam turbines of the Parsons type.

TABLE 1.

60-Cycle Alternators.

Output, in kilowatts.	Speed, in Revolutions per Minute.		Weight, in Pounds.	
	Alternators driven by turbines.	Alternators driven by reciprocating engines.	Alternators driven by turbines.	Alternators driven by reciprocating engines.
400	3 600	150	16 000	34 000
750	1 800	120	32 000	52 000
1 000	1 800	100	38 000	97 000
1 500	1 200	100	45 000	97 000

25-Cycle Alternators.

Output, in kilowatts.	Alternators driven by turbines.	Alternators driven by reciprocating engines.	Alternators driven by turbines.	Alternators driven by reciprocating engines.
1 500	1 500	83	56 000	100 000
5 500	750	75	225 000	910 000

The 5 500-kw. alternator, operating at 75 rev. per min. and weighing 910 000 lb., is the machine constructed by the Westinghouse Company for the Manhattan Railway Company and for the Interborough Rapid Transit Company in New York City, and is usually referred to as a 5 000-kw. machine. Its comparatively great weight and dimensions are due to the fact that it is of the so-called "fly-wheel" type, *i. e.*, the rotating element constitutes at once the revolving field of the alternator and the fly-wheel of the engine, the smaller machines in the same list using, in all cases,

auxiliary fly-wheels in addition to the rotating elements of the alternators. Chief Engineer Lamme, of the Westinghouse Company, estimates that the diameter of the rotating element of a 5 500-kw. 25-cycle machine of the type using an auxiliary fly-wheel and operating at 75 rev. per min., would approximate 25 ft. while its total weight would be 600 000 lb. While the elimination of the usual auxiliary fly-wheel is chiefly accountable for the less ratio of output to weight which characterizes this machine as compared with others referred to in Table 1, the fact that it is wound for 11 000 volts while the others are wound for 6 600 volts, and that its regulation upon non-inductive load is approximately 5%, as compared with regulation of from 6 to 8% in the other cases, are also contributing causes.

The writer is indebted to the General Electric Company for interesting information relating to the new lines of dynamos which that company is constructing for operation in connection with the Curtis steam turbine. In these machines the shafts are vertical, the rotating element of the dynamo being carried immediately above the turbine upon the extended shaft of the latter. The shaft is supported by an oil-thrust bearing to which oil is supplied under high pressure.

TABLE 2.

60-Cycle Alternators.

Output, in kilowatts.	Speed, in Revolutions per Minute.		Weight, in Pounds.	
	Alternators driven by turbines.	Alternators driven by reciprocating engines.	Alternators driven by turbines.	Alternators driven by reciprocating engines.
500	1 800	107	11 100	88 000
5 000	514	75	158 000	507 000

25-Cycle Alternators.

5 000	514	75	218 000	531 000

The abstracts from lists of standard sizes, given in Table 2, again strikingly illustrate the great reduction in the weight of the dynamo, which results from the higher speed of the turbine.

The 500-kw., 60-cycle turbine-driven alternator listed in Table 2, is wound for 2 300 volts; the engine-driven alternator of the same output is wound for 13 200 volts.

As regards 25-cycle machines intermediate in size between the 500 kw. and 5 000 kw. mentioned in Table 2, comparison may be made between a 1 500-kw., engine-driven alternator operating at 75 rev. per min. and weighing 162 000 lb. and a 2 000-kw., turbine-driven machine operating at 750 rev. per min. and weighing 79 000 lb.

It should be noted that by reason of the very high peripheral speeds used in turbine-driven dynamos, their cost decreases less rapidly than their weight as compared with those driven by reciprocating engines, the high peripheral speed involving, of course, the necessity of greater strength in the revolving element, which greater strength must be obtained by using stronger material or better design, or both.

Increase of Potential of Dynamos.—Alternators are now frequently wound for potentials which were practically impossible ten years ago. This is in part due to improved design but, in greater degree, it is due to improved insulating material. Flexible and easily worked sheets or strips of cotton cloth, cambric, etc., impregnated with special oils and capable of withstanding very high potentials, are now available in variety and quality far surpassing anything to be had ten years ago, and skill in building up composite insulation composed of thin sheets of mica overlapping and cemented together and to a cloth backing by varnish, has reached a point where this excellent insulating material is now most extensively used.

Sheets of so-called micanite, subjected to great pressure and temperatures exceeding any attained in the operation of the dynamo, are shaped and moulded into a variety of useful forms which were not available at the beginning of the decade. In America, machine-wound armature coils are preferred, while in Europe the more usual practice is to wind the armature by hand. The difference in cost of labor may have, perhaps, something to do with this difference in methods, but American practice has been influenced largely by the idea of facilitating repairs. This consideration is of far less relative importance to-day than it was fifteen

or even ten years ago as the marked improvement in insulating materials, and in the method of their application, has gone far toward the elimination of break-downs due to failure of the dielectric under potential strains, which in the early days of commercial use of the dynamo so frequently occurred. It is noteworthy that Continental practice has led American practice in the gradual increase of potential, the 13 000-volt machines at Paderno being constructed about the time that the first 6 600-volt alternators were built in America, while the 20 000-volt machines used to supply power to the Valtellina Line in Italy were practically contemporaneous with the first 11 000-volt alternators in the United States. It is only fair to American practice, however, to say that the factor of safety in insulation of the 20 000-volt machines referred to, is materially less than in 11 000-volt alternators of American manufacture.

Efficiency of Dynamos.—Improvement in efficiency has been less marked than improvement in insulation for the excellent reason that the state of the art ten years ago left more room for improvement in the latter than in the former. Some of the dynamos designed ten years ago were so efficient that but little gain was possible, *e. g.*, the commercial efficiency of the first three Niagara alternators was 96.75 per cent. The efficiency of the next seven alternators exceeded 97%, and the efficiency of the latest machines of the same type is practically the same. The average gain in efficiency, however, has been greater than would be indicated by a comparison of the earlier and the more recent Niagara generators. This gain has been due to improvements in design and to improvement in the magnetic properties of the sheet steel of which the armature cores are composed. Improvements in design have resulted in a reduction of the losses due to magnetization of the iron, effected by better proportioning of the quantity of iron magnetized and the intensity of magnetization, and also by some reduction in length and increase in cross-section of the copper circuits traversed by the armature and field currents. Indirectly also, the losses have been reduced by improved methods of ventilation which have resulted in lowering the maximum temperatures attained in operation. There has also been some improvement in the conductivity of average commercial copper available in dynamo

manufacture, resulting in further slight decrease in losses due to resistance.

In the manufacture of continuous-current dynamos, little if any change has occurred during the last ten years in respect to potentials for which machines of this class are wound, the practical limit for those of constant potential and large output, now, as then, not exceeding 750 volts. The usual commercial potential for railway service is 550 volts and for general lighting and power service either 220 or 110 volts. In continuous-current dynamos delivering constant current at variable voltage, there has been a strong tendency to increase the potentials commonly used in arc-lighting service, dynamos of this type, developing from 6 000 to 7 000 volts at their terminals, having been extensively introduced.

Regulation.—The potential regulation of alternators has been greatly improved in recent years. In the design and construction of continuous-current dynamos, it is easy to obtain a practically constant difference of potential at terminals under loads varying from zero to full rated output by using the well-known compound field winding, but in the case of alternators, although various expedients aiming to accomplish a similar result have been proposed, no equivalent of the compound winding of the continuous-current dynamo is generally used. In the early design of alternators of large output, also, at least in America, there was some hesitation for a time in attempting to obtain very close potential regulation, difficulty being apprehended in the construction of switching devices adequate to deal with the tremendous currents which such alternators produce under conditions of short-circuit. Remarkably effective switches, automatic and otherwise, are now available, and it is usual to make the fields of alternators very powerful magnetically as compared with the reactive effect of the armature winding, with the result that potential regulation of 6%, and even 5%, between limits of full load and no load is not uncommon, while regulation exceeding 8% is not considered good practice.

Ventilation.—Perhaps nothing during the last ten years has accomplished more substantial results than the close attention which designers, during that period, have bestowed upon the question of dissipating internal heat. Improvement in this regard, which has been effected chiefly by the liberal use of ventilating spaces in the

body of the armature core, and by predetermination and utilization of the air currents established by rotation of the revolving element of the machine, has been very marked. Substantial gain has also resulted from the practice of building up field windings by bending on edge uninsulated copper strap of rectangular section, adjacent layers of the spiral thus formed being electrically separated by micanite or other heat-resisting insulating material, such coils being capable not only of withstanding relatively high temperatures without deterioration of insulation, but also by their construction, dissipating heat rapidly from the exposed faces of uninsulated metal. Improvement in heat-resisting properties of the insulating material has done much to increase the reliability and durability of dynamos, and the more effective ventilation provided has resulted in a decided increase in ratio of output to weight and cost.

The Adoption of Standards.—In America, great progress has been made in the adoption of standards in the manufacture of electrical apparatus. Here, as in Europe, unceasing battle is waged between the manufacturer who desires to avoid special designs and the consulting engineer who aims to secure, for the solution of each problem, apparatus designed with special reference to the particular conditions which he finds himself called upon to meet. In America, while each manufacturer is disposed to complain of the number and variety of the special constructions which he is called upon to supply outside of his established standard lines and sizes, recognition of these standards by engineer and purchaser is far more general than in Great Britain or on the Continent.

The advantages of manufacturing large numbers of machines identical in construction are obvious, and it is probably safe to say that the relatively rapid extension of the use of electric power and lighting machinery in America is due in no small degree to frank recognition of these advantages, not only by the manufacturer but also by the engineer. Advantage results not only in reduction in cost by reason of the repeated utilization of the same drawings, patterns and shop tools, but also in the resultant interchangeability of parts and facility of renewals.

To the general adoption and use of standards of manufacture and practice, the American Institute of Electrical Engineers has contributed influentially and with excellent results by the adoption

of carefully considered definitions and general specifications covering substantially the whole field of electric power and lighting apparatus. The members of the Institute in their engineering practice and the manufacturers in the construction of their product have both shown, in general, their appreciation of the value of standards by manifesting their willingness to be guided by these rules.

Organization of Generating Plants.—During the last decade, the accepted principles of plant organization in the case of continuous-current apparatus have not materially changed. The average size of the generating unit has increased, and the size of the largest available generating units has about doubled, *i. e.,* the largest continuous-current units to-day approximate 2 700-kw. output, while the largest in commercial use ten years ago were about half that rating. The average size of continuous-current installations also has grown materially, installations aggregating 10 000 kw. being not uncommon. The largest installations of this class, however, up to the present time, do not exceed about 15 000 kw.

Practically every installation of this class operates its dynamos in parallel, as has been the custom from the earliest days of the electric lighting and power industry. In the organization of alternating-current plants, parallel operation is now recognized as correct practice, and is almost invariably adopted in important installations. Ten years ago, while it was recognized as theoretically the correct method of operation, it had not been adopted generally, owing to practical difficulties encountered in obtaining sufficiently uniform rotation, in cases where reciprocating engines were used as the prime-movers, and in adjustment of governors to secure proper division of the load. This latter difficulty was encountered not only in the case where alternators were driven by steam engines, but also in cases where hydraulic turbines were used to supply power. The plant installed by Ganz and Company, in Rome, was operated in parallel from the outstart, but at least for a time, the governors of engines, driving the alternators which operated in parallel, were mechanically connected, and in synchronizing one dynamo with another, banks of lamps were used to adjust the load and consequent speed.

In America, the first alternating-current plant operated in parallel was that at Greensburg, Pa., and it was so operated for a

time as early as 1887. The results, however, were not very satisfactory owing to difficulty in securing a proper division of the load, and this method of operation was not adopted in America in any important plant until the installation of the Niagara Falls Power Company began commercial operation in 1895. The 7 500-kw. alternating-current plant used to light the Chicago Exposition comprised ten two-phase machines operating at 60 cycles per sec. They were not operated in parallel, and a very elaborate and complicated switchboard was used to permit the use of any one of the alternating units in supplying any one of the numerous distributing feeder circuits.

The frequency used by Ganz and Company, in Rome and elsewhere, was 42 cycles per sec. That used in the case of the Greensburg plant and many other American plants prior to 1890 was 133 cycles per sec. That used by the Niagara plant was 25 cycles per sec.

Reduction in frequency, as is well known, facilitates parallel operation particularly in respect to the act of synchronizing, *i. e.*, connecting in parallel, with one or more alternators already in operation, another alternator which it is desired to put into service.

Nearly all important alternating-current plants installed during the last decade operate their dynamos in parallel. The ease and certainty with which this highly important method of operation is now utilized, are direct results of the painstaking and scientific work of the designers and builders of the many excellent steam engines now available.

The largest continuous-current installations are not comparable in size with some of our modern alternating-current plants, and in the organization of the latter an interesting feature, not usually adopted in the former, has been developed and is now recognized as standard practice. The writer refers to the operation of the switching devices in the main power circuits by electricity or compressed air. The first plant to use this method was that of the Niagara Falls Power Company, and the agent used was compressed air. The apparatus, installed about ten years ago, is still in successful use, the operator, standing upon a platform with instruments immediately before him measuring potential, current and energy delivered by the several alternators constituting a group

of five, opens and closes the switches in the primary power circuits by manipulating a system of levers which, by admitting and releasing compressed air, actuate pistons which in turn move the switches. The operator thus located at a distance from the power circuits controls them with accuracy in full confidence that no failure of a switch can result in serious physical injury to himself. In the majority of plants using means for operating switches at a distance, electricity now takes the place of compressed air, the power switches being operated by motors or solenoids in combination with spring mechanism to secure rapidity of movement in opening or closing of these control circuits being effected by small switches by continuous current at a potential of 100 volts, the opening and closing of these control circuits being effected by small switches assembled upon a table or benchboard confronted by vertical panels or stands carrying the necessary measuring instruments. In some cases, the control switches are mounted directly upon the instrument panels.

In comparing alternating and continuous-current generating plants, the greater output of many plants of the former type is notable. This is due, of course, to the greater range of alternating-current power transmission, plants of this type consequently being able to supply more extensive territory than can be reached economically by a continuous-current plant. Among the larger alternating-current plants now in operation are the following:

	Output of apparatus installed.	Output of ultimate plant.
Niagara Falls Power Company, Power-House No. 1...	37 300 kw.	37 300 kw.
Niagara Falls Power Company, Power-House No. 2...	41 000 "	41 000 "
Interborough Rapid Transit Company, 74th Street Power-House........	40 000 "	40 000 "
Interborough Rapid Transit Company, 59th Street Power-House........	20 000 "	60 000 "
New York Street Railway Company, 96th Street Plant	38 500 "	38 500 "
New York Edison Company........	38 500 "	56 000 "
Chicago Edison Company........	15 000 "	70 000 "

In the United States, several other plants, comparable with the foregoing, are in course of construction; this is also the case in Great Britain and on the Continent.

Changes in Central-Station Design Resulting from Substitution of Direct Connection for Belt Drive.—During the early years of the last decade in America, general substitution of the direct-connected unit for the belt-driven unit was rapidly effected. In plants using

steam, the engine was in practically every case one of the reciprocating type, the preference of engineers, on the whole, tending with increasing certainty and force toward the vertical engine as contrasted with the horizontal engine. The elimination of the belt and the countershaft resulted in marked economy of space occupied by plants of given output, this economy resulting not only from the more compact assemblage of steam and electric generating mechanism, but also from the substitution of larger units in place of those previously used. High ratio of output to ground space occupied is an advantage visible, not only to the engineer, but also to the business director and stockholder. To this fact and to the further fact that the average plant, located, perhaps, with little thought of future growth, has found itself within a few years cramped by lack of space, is due, in large degree, the promptness and thoroughness with which the work of substitution has been carried out in America, notwithstanding the fact that such substitution involved the necessity of sending to the scrap pile vast quantities of electric and steam apparatus which had not seen ten years' service. It seems unnecessary to illustrate by concrete examples the economy of space which has resulted from the elimination of the belt and the countershaft. Except in small plants or in cases where abnormal conditions may govern the choice of apparatus, these features are now recognized as out of date in first-class plants for the generation of electric power.

Changes in Central-Station Design Resulting from Use of Turbines.—Space Occupied.—Any extended reference to the relative use of steam turbines and reciprocating engines would be outside of the intended scope of the subject, but it is difficult to discuss the comparative features of dynamos driven by turbines and those driven by reciprocating engines without including a few general statements relative to these respective prime-movers. In marine work, the reduction in dimensions and weight which results from substitution of the turbine for the reciprocating engine is of the utmost value. On land, it is far less important, and comparison of the ratio of output to area occupied, in the case of some of the largest and most modern plants using respectively prime-movers of the two contrasted types, fails to demonstrate any material advantage of the turbine in this respect. This is, of course, due to the fact

that the vertical reciprocating engine occupies a small fraction of the total area of a plant. The general features of plant organization being similar, the spacing of the boilers usually fixes the proper centers for the engines or turbines, and such advantage of the turbine as it possesses in respect to floor dimensions is partially, if not wholly, offset by the increased size of the condensers. The difference in height of the turbine-driven unit and the unit driven by the reciprocating engine affects only the height of the engine room, and this involves no material difference in cost. As regards area covered, a comparison may be made, for example, between the plant of the Manhattan Division of the Interborough Rapid Transit Company, in New York City, and the plant now under construction in Chelsea, London, for the London Metropolitan Underground Railway Company, the alternators for both these plants having been supplied by the same manufacturer. In both these plants, two decks of boilers are used. The power-house of the London company covers an area of 84 960 sq. ft. It is designed to contain three turbine-driven units rated at 5 500 kw. each, and two units rated at 2 000 kw. each. The ground space occupied, therefore, is 1.44 sq. ft. per rated kilowatt.

The power-house of the New York company covers an area of 85 072 sq. ft., and contains eight alternators driven by reciprocating engines. The corresponding rating of the alternator unit of each type is 5 500 kw., and the writer believes it safe to say that the generating unit used by the New York company is able to take care of any overload to which the turbine-driven unit is adequate. The area covered by the New York power-house is 85 072 sq. ft., and the area per rated kilowatt output, therefore, is 1.93 sq. ft.

To make the comparison more fair, the two units of 2 000 kw., each, included in the design of the London station, should be excluded, for it would have been possible to install in the New York plant units of similar output, similarly located and driven by reciprocating engines, had the use of auxiliary units of relatively small output appeared desirable to the engineers who designed that plant. Making the deduction of 4 000 kw. of the Chelsea plant, the areas per rated kilowatt output become for the London plant 1.55 sq. ft., and for the New York plant 1.93 sq. ft. per kw. The Thirty-eighth Street plant of the New York Edison Company, using two

decks of boilers and having its generating units arranged in two rows, which is the plan adopted at Chelsea, is designed for a rated output of 56 000 kw. and occupies less than 54 000 sq. ft., *i. e.,* less than 1 sq. ft. per rated kilowatt output.

The most conspicuous examples of power-houses using but one deck of boilers are those recently erected, respectively, by the Chicago Edison Company and the Interborough Rapid Transit Company, New York City, the latter being located on the North River between Fifty-eighth and Fifty-ninth Streets. The ground space covered by the Chicago plant, including switch-rooms, is 171 000 sq. ft., and its ultimate equipment will comprise fourteen 5 000-kw. turbines. The space occupied, therefore, is equivalent to 2.44 sq. ft. per rated kilowatt. The ground space occupied by the plant of the Interborough Rapid Transit Company is 692 by 200 ft., and it is designed to contain twelve units driven by reciprocating engines. These units were purchased under specifications calling for 5 000-kw. machines, but they are rated by the manufacturer at 5 500 kw. If the former rating is taken, the space occupied per kilowatt output is 2.30 sq. ft., or if the manufacturer's rating is accepted, it is 2.09 sq. ft. It appears, therefore, *prima facie,* that the use of the turbine does not imply material economy in dimensions of the site requisite for a large electric power plant, and it is probable that an accurate comparison, having reference, not to rated output of the generating units, but to actual safe output under operating conditions, would show results even less favorable to the steam turbine. Accurate data regarding ability of the turbine units to carry overloads with good economy, and without excessive temperature, however, are lacking, since no large turbine-driven plant hitherto has been operated under commercial conditions adequate to determine satisfactorily its limitations in respect to overload.

If the steam turbine ultimately supplants the reciprocating engine in electric power plants, the change will be made not because there is any controlling difference in the ground space occupied, but by reason chiefly of other and more important advantages. Among these may be mentioned the fact that the turbine is comparatively small and light and in due time will be relatively cheap. Its high speed also tends to reduce materially the cost of the direct-connected dynamo, as has been shown in this paper. The advocates of the

turbine also claim important fuel economy, particularly under variable loads, but this claim has not been effectively substantiated in commercial service. The foundations required for turbines are much less expensive than those called for by reciprocating engines.

Progress in Transmission.

As regards transmission of continuous current used for lighting and general power purposes, underground circuits in large cities of the United States and in many important towns of less size have, in very large degree, displaced overhead circuits. Improvement in quality and reduction in cost of insulated lead-sheathed cables have resulted from the competitive efforts of many manufacturers in America and Europe, and these improvements, in connection with the development of higher æsthetic standards in urban communities, have resulted in a gratifying reduction of the amount of overhead construction in this class of service. In connection with continuous-current distribution for the operation of electric street-car service, relatively less progress in substituting underground for overhead construction has been made, but in some of the most important cities, notably in Washington and in the Borough of Manhattan, City of New York, the greater part or all of the street-car service is supplied without any overhead construction whatever. In a number of cities, while the overhead-trolley wire is used, the feeder circuits in whole or in part have been placed underground.

Transmission by alternating currents has undergone remarkable development in the last ten years. Power to the amount of 10 000 kw., developed by mountain streams, is transmitted to cities and towns in California located at distances ranging from 154 to 218 miles from the generating stations. These plants use 40 000 volts for the transmitting circuits. Buffalo is supplied with more than 18 000 kw. from Niagara Falls. Montreal is receiving power from the Shawinigan Falls over circuits 85 miles in length, operating at 50 000 volts, and the plant of the Guanajuato Power Company in Mexico is successfully delivering power over circuits 101 miles in length, and operating at 60 000 volts.

Transmission plants which ten years ago would have been regarded as remarkable now attract little or no attention as they are successively placed in commercial operation. Lists of alternating-cur-

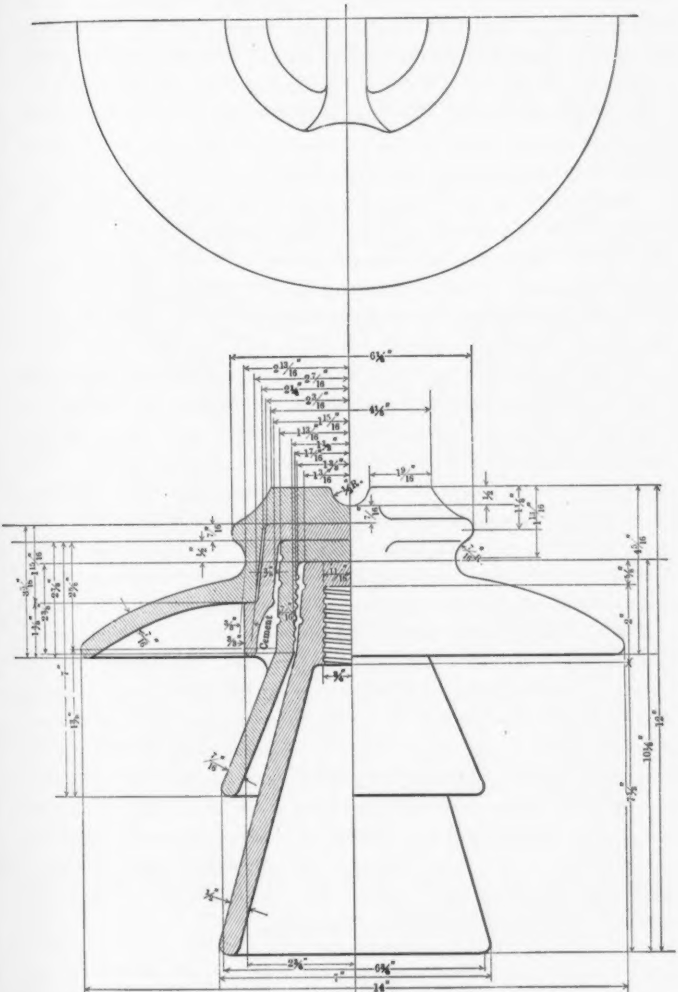


FIG. 1.

rent transmission plants recently furnished by the three leading American companies manufacturing this class of apparatus, show that they have installed in the United States, Canada and Mexico, 447 plants, aggregating 734 123-kw. output. The potentials range from 125 to 60 000 volts, and the distances of transmission vary from a few feet to 218 miles. The limits of this paper forbid even brief reference to very many points of interest; only a few of the more salient and important facts can be mentioned.

The highest potential in commercial use is 60 000 volts; the longest distance over which power is electrically transmitted is 218 miles. The largest copper conductors used in America for overhead transmission at a potential exceeding 20 000 volts are of 350 000 cir. mils. section, and the largest aluminum conductors similarly used are of 500 000 cir. mils. section.

An idea of the range and efficiency of electric transmission, using potentials now in commercial use, conductors of sizes now in commercial use and transmitting power to the maximum distance thus far attained in commercial operation, may be conveyed by the statement that at 60 000 volts a three-conductor circuit comprising three copper conductors of 350 000 cir. mils. each will transmit 7 500 kw. (10 000 e. h. p.) a distance of 218 miles with a loss in the transmitting circuits which, making due allowance for the wattless component of the current, will not exceed 10 per cent.

Improvements in the art of transmission effected by changes of the systems used—the introduction of the alternating-current system sometimes as successor to the continuous-current system, sometimes in combination with the latter to increase the radius of transmission—have been referred to previously in this paper. It remains now to note, and necessarily very briefly, improvements in respect to certain specific apparatus used in electric transmission, and it may be well to consider (1) certain apparatus used in transmission by overhead circuits; (2) apparatus used in transmission by underground circuits; and (3) apparatus common to both overhead and underground transmission.

Overhead Transmission.

In the art of transmission by overhead circuits, advance may be noted particularly in respect to insulators, lightning arresters, and in the use of steel towers instead of poles.

Insulators.—The dimensions and form of the insulator used for the 60 000-volt transmission at Guanajuato are shown in Fig. 1, and for purposes of comparison the so-called Type *C* insulator used in the Niagara-Buffalo transmission in 1896 is shown in Fig. 3. As representing an intermediate step in development, Fig. 2 shows the dimensions of the Type *E* insulator used in the con-

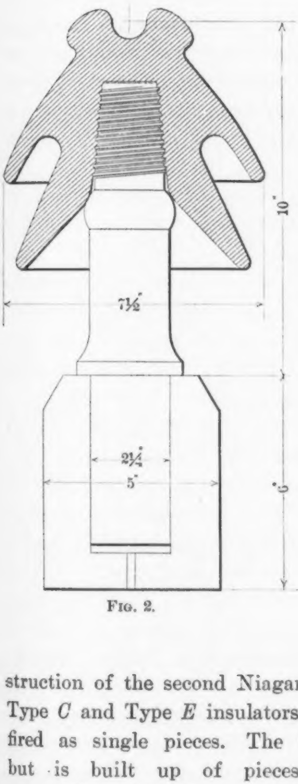


Fig. 2.

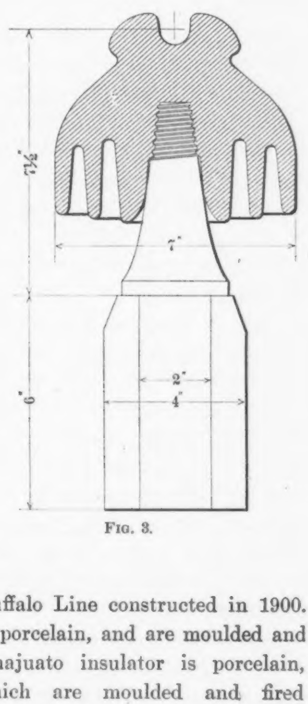


Fig. 3.

struction of the second Niagara-Buffalo Line constructed in 1900. Type *C* and Type *E* insulators are porcelain, and are moulded and fired as single pieces. The Guanajuato insulator is porcelain, but is built up of pieces which are moulded and fired separately, and subsequently assembled and held together by a special cement or glaze. Manufacturers of porcelain find it

extremely difficult to produce single-piece insulators of dimensions materially greater than those of Type *E*, owing chiefly to the fact that as dimensions increase, differences between maximum and minimum thicknesses of the porcelain necessarily increase, and it becomes almost impossible to fire properly and uniformly all parts of the insulator. In cooling, moreover, the differences in thickness tend to cause shrinkage cracks, weaken the insulator and cause it to break readily under test or subsequently in service. For very large insulators, therefore, best results are attained by composite construction, as illustrated in the Guanajuato insulator, since by this method of manufacture the difficulties resulting from difference in thickness and rate of cooling are in great measure avoided. American porcelain, although much improved during the last decade, is not yet equal to the best grades used in Europe in the construction of insulators.

Line insulators obviously must be designed to resist puncture by high potential which tends to strike through from the conductor to the pin, and also to prevent the establishment of a circuit from the conductor across the surfaces of the insulator. Improvement in quality of the material used implies, to some extent, the possibility of using higher potential with given thickness of porcelain between conductor and pin, but the greatest gain that has been made is in the approach to perfect homogeneity of the porcelain.

Lightning Arresters.—The protection of overhead transmission circuits against lightning has received much attention from investigators and inventors since dynamic electricity was first used to transmit energy. In the earliest days of alternating-current development in America, arresters of a type which had been used with considerable success for the protection of apparatus used in telegraph service, were tried, but more than ten years ago their utter futility in protecting constant potential circuits supplied by dynamos of large power had been demonstrated. Several interesting types of arresters had been proposed and more or less experience acquired in their use. Among these, Elihu Thompson's magnetic blow-out arrester had proved its effectiveness in protecting continuous-current constant potential circuits such as are used in supplying continuous-current series arc-lamp systems. This arrester is still in very extensive use and is generally regarded as

effective and satisfactory. For the protection of constant potential alternating-current circuits, which class comprises practically all long-distance transmissions, the so-called "non-arcing metal" arrester discovered by Wurts was beginning to demonstrate its fitness to survive the majority if not all of its rivals. Attached to this class of circuits, the arrester must perform the double function of preventing abnormal rise of line potential and suppressing the arc which tends to form across the air gap when the discharge passes to earth. Fig. 4 illustrates the essential parts of one of the latest forms of arrester in which non-arcing metal is used. Seven brass cylinders, each approximately 3 in. in length and 1 in. in diameter, are mounted parallel to each other, separated by air gaps approximating $\frac{1}{32}$ in. A moderate resistance is connected in series with the cylinders and between them and earth, while a higher resistance is connected in shunt around three of the gaps. The number and width of the series gaps are adjusted for a reasonable factor of safety with reference to line potential with one line of the circuit grounded. The shunted gaps provide a path for the lightning discharge, which, if of any considerable quantity, is unable to pass through the shunt resistance without dangerous rise of potential on the line. The shunt resistance helps to suppress the arc across the shunted gaps, and after the passage of the discharge and when the arc across these gaps is suppressed, it limits the current across the series gaps and so assists in the final suppression of the momentary discharge.

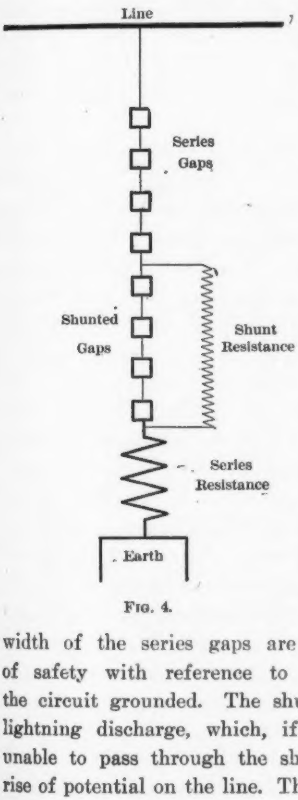


FIG. 4.

In the best American practice in protecting high potential alternating-current transmission circuits, paths to earth are provided

by several arresters connected to each line of the circuit, and between each two successive points at which the arresters are connected to the line a reactance coil is introduced in the line circuit to aid in preventing the lightning discharge reaching transformers or dynamos, and compelling the discharge to go to earth across the air gaps provided for the purpose. Of course where the line potential exceeds 6 000 volts, the number of cylinders and air gaps and the proportions of the shunt and series resistances are increased.

Use of Steel Towers.—The plant of the Guanajuato Power Company not only uses higher potential than had been adopted previously in commercial service, but the construction of its transmission circuits marks an important step in progress by the substitution of steel towers for wood poles, and the use of an average span of 440 ft. instead of the usual shorter spans, which range from 70 ft. to approximately double that distance. The plant has been in operation for nearly a year and is said to have operated during this period with entire success. The towers used are of galvanized steel and are similar in general design and construction to the towers commonly used in America for windmills. Taking into account the cost of cross-arms and insulators, a line thus constructed should be, in general, no more expensive than the ordinary wood-pole line while, properly designed, it is of course far superior with respect to durability and appearance. Some engineers oppose the use of steel poles or towers in connection with iron cross-arms and insulator pins on the ground that to substitute for wood in the construction of pins and cross-arms a material of high electrical conductivity is ill-advised because it reduces the insulation of the circuits. Undoubtedly it tends in this direction, but the experience of the Guanajuato Power Company seems to demonstrate that insulators, which may be depended upon to secure effective electrical separation of the several wires of the circuit, are now available, and from a mechanical viewpoint the steel tower seems so far superior to the wood pole that its speedy general adoption in transmission installations of importance may be hoped for. In Europe it may be noted that steel poles have been used for a number of years in some of the more important transmission installations, notably that between Paderno and Milan, in which the potential used is

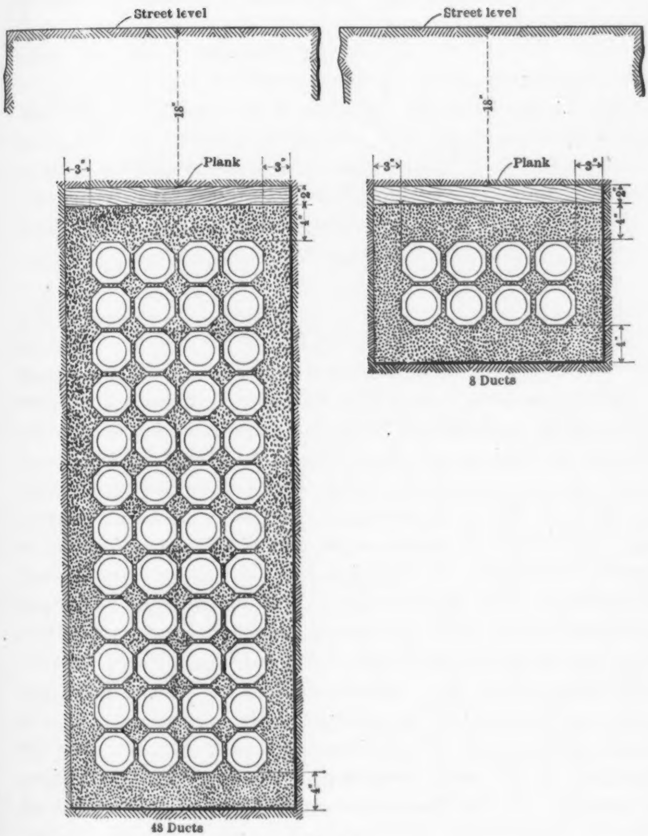

Street level
18"
3"
Plank
3"
2"
4"
4"
43 Ducts
Street level
18"
3"
Plank
3"
2"
4"
4"
8 Ducts

FIG. 5.

13 000 volts, the distance of transmission being approximately 35 miles.

It is appropriate to mention here the daring and successful tower construction used by the engineers who designed the transmission circuit which crosses an arm of the bay near San Francisco. In this case, the span is 4 227 ft., the conductors being steel cables $\frac{7}{8}$ in. in diameter; three of these conductors are carried by steel towers. The tower on the north side of the bay is 225 ft. in height, while the tower on the south side is 65 ft. in height. The design and construction of the insulating saddles, which perform the double function of insulating these cables against working potential of 40 000 volts and of mechanically supporting so long a span, are notable engineering achievements.

Underground Transmission.

Cables.—One of the most important gains in the last ten years is the marked improvement in reliability of insulation and in cost of insulated lead-sheathed cables for high potential underground circuits. The advance is due chiefly to the evolution of oil-treated paper. In the manufacture of these cables, the conductor is covered by strips of Manila paper wound on spirally in such number of layers as is requisite to secure the desired thickness of insulation, and the conductor thus covered is immersed in a vat containing a resinous oil at boiling temperature. This immersion continues until the paper is thoroughly impregnated by the oil, all air and moisture apparently being excluded from it by this process. When the treatment is completed, the conductor—or several of them if the cable under construction is of the multiple-conductor type—is covered by a lead sheath usually about $\frac{1}{8}$ in. in thickness, the function of this sheath being mechanical protection of the insulation and exclusion of moisture. During the last decade, cables of this kind have come into very extensive use and have proved very successful. As compared with rubber-insulated cables of anything like equal cost, they are generally considered superior and it seems probable, if the lead sheath be preserved and moisture effectively excluded from the insulation, that a cable thus insulated will outlive much more expensive rubber-insulated cable. An interesting and in some respects most

excellent cable recently placed upon the market uses, as insulation, cambric impregnated by a special oil. This insulation appears capable of withstanding temperatures in excess of those recognized as the practical working limits in the case of rubber and paper, and apparently it is also less liable than paper to rapid deterioration in case the lead sheath should be punctured.

Conduits and Manholes.—Material improvement in the construction of electric conduits and manholes has been effected within the last five or six years, but even now a very large proportion of the conduits put down and manholes provided are not well designed for their purpose. Fig. 5 illustrates a correct arrangement of ducts in a conduit constructed for cables intended to carry heavy power currents, and Fig. 6 illustrates a typical manhole. The ducts being arranged twelve high and four wide, it will be observed that on at least one side no duct is separated from the surrounding earth by more than one duct. Tests carried out by the writer six years ago at Niagara demonstrated that even with this arrangement the temperature attained by cables in ducts separated from earth by one outer layer of ducts exceeds the temperature attained in the outer layer by about 20° cent. when the loss in cables is 5.5 watts per duct foot.* If conduits be constructed of six layers, each layer comprising six ducts, the temperature attained in some of the interior ducts will be so great as to reduce materially the amount of power which can be conveyed through them with safety. In the construction of manholes, it is apparently rare to find adequate dimensions allowed. Frequently this results from the fact that the electrical engineer does not design the manhole, this part of the work in the organization of many American companies being left to men who are supposed to know more than the engineer does about excavation and brickwork. The result sometimes is disastrous. Expensive conduit systems are constructed and a considerable portion of the ducts is found to be worthless by reason of the fact that the provision for locating and racking these cables in the manholes is entirely inadequate.

As regards material used in the construction of ducts in America, vitrified clay is used far more extensively than any other. Conduits of wood fibre treated with preservative compound are also

* *Transactions*, Am. Inst. Elec. Engrs., Vol. XVIII, p. 541.

available at reasonable cost, and iron pipes are used not infrequently in cases of special construction, particularly where ducts must, for local reasons, materially change their direction between manholes.

The Transformer.—Transformers are almost invariably used at

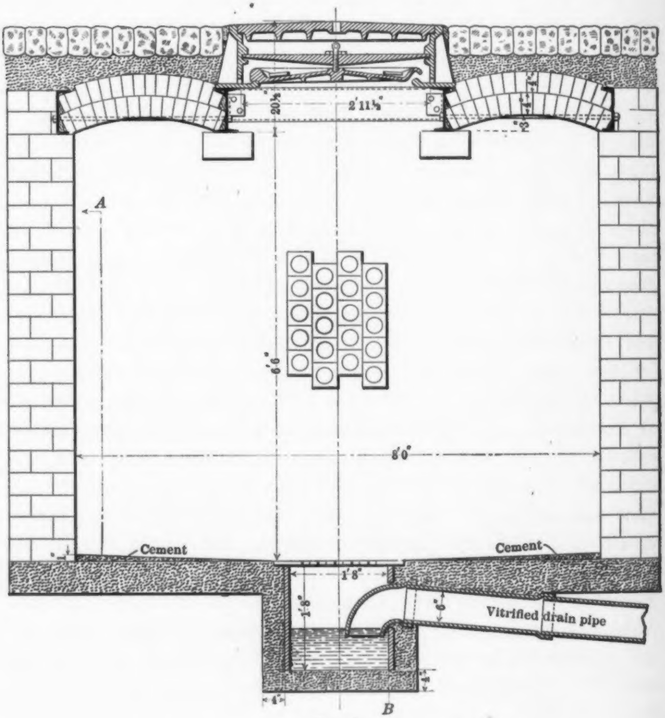


FIG. 6.

the receiving end of alternating-current transmission circuits. They are, as has been stated, also frequently used at the power-house. This highly important apparatus—the key to the art of electric power transmission—had attained a high degree of excellence ten years ago.

About that time, 930-kw. transformers wound for secondary potentials of 11 000 to 22 000 volts were constructed, and they are still in use, their efficiency by test exceeding 97.8 per cent. But while transformers ten years ago were highly efficient and well insulated, material improvement has resulted since then from the increasing science and skill of designers and builders. As in the construction of alternators, so in transformers, considerable gain has resulted from the improved quality of sheet steel now available. In respect to the steel, advance in knowledge of the phenomenon designated aging, *i. e.*, the gradual deterioration in magnetic qualities due to heat, has received particular attention and is now in large degree preventable. The inductive drop has been reduced by better relative disposition of primary and secondary windings and, particularly, by the expedient of dividing each of these windings into several coils. In building up such a transformer, the constituent coils of the two windings are alternated; first a coil of the primary, then one of the secondary, then one of the primary, then another of the secondary, and so on, the result being that practically all of the magnetic lines of force due to currents in the primary are cut by the secondary winding. The first constant potential transformers made in America regulated within about 6%, but the largest of these transformers was of only 2-kw. output. The first larger ones were of 2.5-kw. output, and when tested it was found that their variation of external secondary potential between no load and full load was 19 per cent. This led to speedy investigation of the causes of drop in transformers, and as far back as 1889 it was found by actual test of a 2-kw. transformer, in which the primary and secondary circuits were adjacent throughout their entire lengths, that with ideal relative position of primary and secondary windings the total drop would not exceed, by an amount measurable by ordinary laboratory instruments, the drop due to resistance. To this ideal relation of primary and secondary windings, practice has gradually approximated, particularly in the design of large transformers, and to-day regulation within 1½% with power factor of 100 is commonly attained.

Progress in construction for high and still higher potentials has been marked. For potentials exceeding 25 000 volts, oil is usually depended upon as the insulating medium to secure effective separation of the primary and secondary circuits from each other and of

both from the iron core. For potentials not exceeding 25 000 volts, transformers commonly designated "air-insulated" are extensively used, although the oil-insulated type is also used for potentials as low even as 1 000 volts. In the so-called air-insulated transformers, electrical separation is obtained, where primary and secondary coils are in close proximity to each other or to the iron core, chiefly by cambric, cotton cloth or paper impregnated with special oils of high insulating properties, the cloth or paper being prepared by processes of frequent immersion and drying until, in the resultant sheet material, the paper or cloth may be said to constitute, practically, the mechanical skeleton of the sheet of oil insulation. The coils are so spaced with reference to each other and the core of the transformer, that air under pressure of from ½ to 1 oz. in quantity sufficient to prevent excessive rise of temperature will circulate through openings provided for the purpose. Ventilation by forced draft is unnecessary in transformers of the smaller sizes, but those exceeding 50 kw. which do not use oil commonly use the forced-draft method of cooling, the necessary air being supplied by motor-driven fans. Oil-insulated transformers of self-cooling types are made in various sizes up to a rated output of 400 kw. In the construction of primary and secondary coils of oil-insulated transformers it is usual to make no attempt to secure a high degree of insulation by covering the several coils with insulating material such as oiled cambric, etc., but reliance is placed, chiefly or wholly, upon the oil in which the transformer, when assembled, is immersed. Predetermined spacing between the frequently numerous constituent coils which are connected to form the primary and secondary circuits is preserved by strips of micanite or other insulating material possessing the necessary mechanical strength and rigidity, and through these spaces, as the transformer warms up in service, the oil circulates naturally by reason of local differences in its density due to expansion caused by heat. A study of the design of a modern transformer of this class is one of great interest, and the problems presented are such as have demanded and received the attention of many of the most scientific and ingenious designers in the electrical field.

In oil-insulated transformers of the larger size, *i. e.,* roughly those which exceed 400-kw. output, several means for cooling the oil are adopted. In general, the usual method is to immerse in the oil

at points where it attains its highest temperature coils of brass or iron pipe through which water at low temperature is circulated, the heat of the oil thus being carried off by the water. In a few cases, the large conductors of the secondary circuits have been made in the form of flattened pipes, and water has been circulated through the interior of these pipes which thus serve a double purpose. In the present state of the art, there is no doubt that transformers for potentials exceeding the highest now used in the transmission of power, *viz.*, 60 000 volts, can be constructed, as is sufficiently evidenced by the fact that for testing purposes, transformers delivering potentials up to 200 000 volts are in use.

Organization of Circuits.

In a brief survey of progress in the organization and connection of transmission apparatus, two devices, neither of which is ten years old, while both contribute materially to maintaining continuity of service over transmission circuits, may be noted. These devices are the time-limit automatic circuit-breaker and the reversed current circuit-breaker. The former is used to localize interruptions of service resulting from short-circuit, and accomplishes this by using automatic circuit-breakers which can operate only at the expiration of predetermined intervals following occurrence of the short-circuit, circuit-breakers opening in minimum time being used in the more remote branches of the general power supply, while circuit-breakers connected in series with these but nearer the source of power can open only at the expiration of longer intervals of time. When a short-circuit occurs in a given branch of the system, therefore, the flow of current is promptly interrupted by the circuit-breaker on the branch, and as the opening is effected before the time mechanism of the main line circuit-breaker has reached the predetermined limit where it operates to trip the breaker the latter is not opened and the general service is not interrupted.

Reversed current circuit-breakers are used sometimes between dynamos and bus-bars in the power-house, and occasionally at the receiving ends of two or more transmitting circuits which are connected in parallel in the sub-station. When thus used, they serve, in conjunction with over-load circuit-breakers at the generating

ends of the transmission lines, to cut out of service automatically a line which may be accidentally short-circuited. The function of the reversed current circuit-breaker is most important. Unfortunately, up to the present time, it has not been developed to a point where its practical operation may be considered thoroughly satisfactory.

Storage Batteries.

In America the commercial use of storage batteries, except upon a very small scale, practically dates from 1894, and the aggregate of batteries installed in the United States during 1895 probably did not exceed 4 000-kw-hr. upon 8-hr. rating. To the Electric Storage Battery Company, which installs probably about 90% of all storage batteries used in America, the writer is indebted for Table 3, showing battery installations for different classes of work to August 1st, 1904. The outputs are rated with reference to 8-hr. discharge.

TABLE 3.

In electric-lighting central-station work.....	146 814	kw-hr.
In railway service..........................	193 889	"
In isolated plants..........................	30 598	"
In train lighting..........................	11 937	"
In telephone service.......................	6 336	"
In Government service.....................	5 522	"
In yacht service...........................	2 793	"

There appears to be an increasing tendency to use batteries, particularly in connection with street-railway plants for regulating, for carrying a part of the peak load and for balancing load on feeders to reduce cost of transmitting conductors. The batteries themselves and their various auxiliaries have been greatly improved during the decade. The switching arrangements for cutting in and out the end cells of a battery are now well made, from a mechanical as well as an electrical standpoint. Much thought and work also have been expended in improving the construction of tanks to prevent warping and splitting; and the booster, a com-

pound-wound, continuous-current dynamo, used frequently in conjunction with the battery to assist it in charging or discharging, has proved itself a most valuable adjunct.

Conclusion.

It is difficult, if not impossible, within the limits of this paper, to sketch satisfactorily the progress of the last ten years in a subject so complex and so extensive as that of the electric generation and transmission of power. Obviously, also, much depends upon the point of view and that which to the writer may appear correct in proportion and perspective may to others, perhaps more competent to judge, appear altogether distorted. Any attempt, therefore, to summarize a paper which in itself is simply a sketch must be hazardous, but in closing it seems desirable, nevertheless, to point out that while the last ten years have been characterized by material progress in the design and construction of electric apparatus used for the generation and transmission of power, it would be quite erroneous to infer that electric apparatus is not to-day fairly comparable to other classes of mechanism used in the industrial arts in respect to stability and permanence of type. It is true that the line insulators of 1894 are, with rare exceptions, no longer used, that lightning arresters during the last decade have been much improved, that oiled paper has largely superseded rubber as insulation for underground cables conveying high potential currents, that the switches now used for high potential alternating currents of large power are unlike anything thought of ten years ago, that dynamos and transformers, as now built, are more efficient and durable, and that in the best plants of to-day important features in the organization and connection of circuits and in the use of automatic circuit-breaking devices have been introduced which in 1894 were not conceived, but it is not true that a majority of electric apparatus essential to the generation and transmission of electric power is now in a stage of rapid development. On the contrary, changes in respect to the specific apparatus just mentioned have been relatively slight during the last five years. They were much more radical in the first five years of the decade, and the opinion may be advanced, perhaps with safety, that dynamos, transformers, switches, measuring instru-

ments, insulators, lightning arresters, cables, conduits, circuit-breaking devices, automatic and other, as now available on the market, have reached a reasonably stable condition in the evolution of the art, and in respect to these constituent parts of electric systems for generation and transmission of power, no such rate of change, as has been observed during the last ten years, is likely to occur during the coming decade.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS, 1904.

DISCUSSION ON

ELECTRICAL POWER—GENERATING STATIONS AND TRANSMISSION.

BY MESSRS. G. PUENTE, Z. T. DANIEL AND N. A. ECKART.

G. PUENTE, ESQ., Buenos Aires, Argentine Republic.*—The speaker has had experience with comparatively few gas engines, only one being of relatively large size, 200 effective h. p., but, in his experience, the net results, considering all their advantages and disadvantages, have been that they are not as successful and reliable as steam engines, and, bearing in mind that absolute reliability is paramount in a prime-mover intended to actuate an electric generator, he does not consider their use advantageous, except under certain conditions of coal, feed and condensation water supply, which may warrant the sacrifice of reliability to a certain extent. The speaker's object in this discussion is to obtain Mr. Stillwell's views and experience, which would be very valuable on this most interesting subject, the question of economical prime-movers being one of extreme importance in the Argentine Republic, where the present coal supply is imported at an approximate cost of $7 per ton for Cardiff coal. Mr. Puente.

The manufacturers of gas engines guarantee the coal consumption, but it is the expensive high-grade oil which is indispensable for operation, and which, even so, gives trouble, and is one of the large items of operation, which counterbalances, to a certain extent, the apparently brilliant and economical coal figures.

* Assoc., Institution of Engineers of the River Plate.

Mr. Puente. In regard to the present development of the single-phase motor for traction purposes, Mr. Stillwell has spoken of the use of a voltage of 2 000.

In the Argentine Republic, the municipal regulations are most severe, and it was with the greatest difficulty that even overhead trolley wires at 500 D. C. were allowed to be installed. We know there is no danger when the wires are where they should be—overhead —but they sometimes break and fall, or telephone wires come in contact with them in spite of extreme precautions, and our municipalities, overcautious, perhaps, from an electrical engineer's point of view, are very much opposed to high-tension aerial lines, even in suburban districts.

Mr. Daniel. Z. T. DANIEL, ESQ., Iola, Kans.*—The speaker had occasion to look into the question of the cost of operating a gas engine at a small plant about a year ago. The Otto Gas Engine Company made the proposition, but they could furnish nothing larger than a unit of 100 h. p. The speaker has forgotten just what their guaranty was, but as nearly as he can recall it was about ¾ lb. of anthracite coal per horse power, 480 g., after figuring the cost of the plant as compared with steam plants, and the cost of operation exceeded the cost of interest on the capital of the steam plant.

Mr. Eckart. N. A. ECKART, ESQ., San Francisco, Cal.—Standard practice on the Pacific Coast seems to favor the motor generator set, rather than the rotary converter, not because of any higher efficiency, but because of the very general use of 60-cycle generators by the large power companies of California. While there is little doubt that the rotary converter is superior at 25 and 40 cycles, both as regards cost and operation, at 60 cycles, the motor generator holds preference at least from the operating standpoint.

Quite a number of railroads on the Pacific Coast are supplied with power by the different transmission companies, most of which use 60 cycles.

*Chf. Engr., Kansas Southern Electric R. R.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

NATURAL WATERWAYS.

Congress Paper No. 56.

A REVIEW OF THE DEVELOPMENT OF NATURAL WATERWAYS IN THE NETHERLANDS.

By A. B. Marinkelle, Engineer, Royal Corps of Waterstaat, Utrecht, The Netherlands.

Congress Paper No. 57.

ROLLING DAMS.

By K. E. Hilgard, M. Am. Soc. C. E., Zurich, Switzerland.

Discussion on the Subject by

William M. Hall, Parkersburg, W. Va., U. S. A.
E. L. Corthell, New York City, U. S. A.
Lewis M. Haupt, Philadelphia, Pa., U. S. A.
A. Miller Todd, Vicksburg, Miss., U. S. A.
C. H. West, Greenville, Miss., U. S. A.
Arthur Hider, Greenville, Miss., U. S. A.
K. E. Hilgard, Zurich, Switzerland.

Note: Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 56.

NATURAL WATERWAYS.

A REVIEW OF THEIR DEVELOPMENT IN THE NETHERLANDS.

By A. B. Marinkelle.*

Introduction.

One might rightly ask whether the great Dutch rivers, of which Fig. 1 gives a general survey, are still free streams, following the ways chosen by Nature in their courses to the ocean.

These waterways, which in diluvian times formed by deposits the higher parts of the Netherlands, for a considerable part of its area, in the shallow sea near the coast, and which in post-diluvial times supplied soil for the formation and manuring of the low delta land for many centuries, have generally become artificial products, in the Netherlands of the present time, and have had to submit to the laws Man has laid down for them. Steadily guided, they can only pursue their courses along the fixed ways assigned to them.

The dangers of inundation, to which a considerable part of the Netherlands is repeatedly exposed, at times of floods and when the ice is breaking up and obstructions of ice-floes are formed, have, time out of mind, given rise to a search for means to improve the

* Engineer, Royal Corps of Waterstaat, The Netherlands.

rivers in such a way as to render breaks in the dikes impossible. The inhabitants, for centuries, have carried on this struggle with the great rivers, in order to check their devastating force and transform them into useful ways of traffic; and this end was not fairly well attained until the Dutch Government, in 1850, put the "general improvement of the rivers" on its programme as a definite system. For more than half a century the improvement of rivers has been undertaken energetically, carried on uninterruptedly and partly completed; not, as before, guided by the limited judgment of those whose interests were local only, but under the influence of minds taking a broad view of the whole system.

A detailed description, even a complete enumeration, of the most important river works which have been carried out during the latter half of the preceding century is not pertinent to this subject, it is only necessary to give a synopsis of the development and progress of Dutch rivers during the last decade, together with conclusions concerning the modern way of improving rivers. Yet some previous information concerning the most important river improvements already effected, may not be omitted here.

Though necessity often urged people to take in hand the regulation of the great rivers, these improvements were only partial, and, as a rule, local interests were predominant. At that time a central power with authority to improve the rivers according to fixed principles, did not exist. Moreover, formerly, not only the technical resources required for the great works necessary in connection with the improvement of rivers, as understood for the last half century and now carried out, were lacking, but there was also a lack of sufficient knowledge of the rivers themselves.

Thus, in former centuries, impressed by the repeated breaks in the dikes, and disasters from the water, people feared that the construction and raising of dikes—which are almost always located along Dutch rivers at some distance from the summer bed (sometimes several kilometers)—would raise the river beds more and more by depositing in them between the dikes the sand and mud which is continually carried by the rivers. While, in the beginning of the preceding century, the dread of a general raising of the bottom did not quite disappear, it gave place more and more to apprehension of a general raising of the water level of the rivers at high-water flows in winter.


NATURAL WATERWAYS
IN THE NETHERLANDS.
NORTH SEA
ZUIDER ZEE
NOORD HOLLAND
Amsterdam
Nord Zee Kanaal
Keteldiep
Kampen
Waterway to Zwolle
Zwolle
OVERYSSEL
Katerveer
Yssel
Deventer
Zutphen
GELDERLAND
UTRECHT
Utrecht
'sGravenhage
ZUID HOLLAND
New Waterway
Maassluis
to Rotterdam
Vlaardingen
Rotterdam
Krimpen
Lek
Vreeswyk
Wyk by Duurstede
Lower Rhine
Rhenen
Arnhem
Westervoort
De Pley
Malburgen
Huissen
Old Rhine
Pannerden Canal
Pannerden
Lobith
Emmerich
Upper Rhine
Brielle
Maas
Hellevoetsluis
Dordrecht
Lower Merwede
Upper Merwede
Waal
Tiel
Druten
Nymegen
Mook
Grave
Lateral Overflow at Beers
Lateral Overflow at Heerewaarden
Meuse
Andel
Dam with lift-lock
Dam
Hedel
Hedikhuizen
'sHertogenbosch
Dieze
Haringvliet
Hollandsch Diep
Volkerak
Amer
Geertruidenberg
Keizersveer
Donge
Dordsche Kil
NOORD BRABANT
Zuid Willems Vaart
Upper
Venlo
Tegelen
Roermond
Maasbracht
LIMBURG
GERMANY
ZEELAND
Schelde
Antwerpen
Kempensche Kanaal
BELGIUM
Maastricht
Eysden
Visé
Scale of Miles
0 5 10 20 30 40 50

FIG. 1.

Afterward, it was understood that, though in former centuries rather important shoals and dried-up places, followed by the raising of the water level, were noticed in some branches of the Rhine, *viz.*, in the Lower Rhine and Yssel, these must be considered to have been mainly of local nature, or must be attributed to an irregular and changed water supply to the various branches of the Rhine during various long periods. This irregular water supply, the result of important local changes at the point of separation of the Waal and Rhine, was only brought about naturally by the influence of the current, increased or decreased width of the channel of supply to one branch of the Rhine, to the advantage or disadvantage of the increasing or decreasing width of the channel to the other branch. It was because of the dread of this raising of the bottom, and of the water level, so much feared in former times, increased by the repeated breaks in the dikes, that people, for a long time, continued to look upon the system of "lateral overflows" in the dikes —in the preceding century considered to be the only remedy—as a temporary makeshift in times of flood.

Not until 1850, when the Government took the general improvement of rivers energetically and systematically in hand, on the principle of the current-courses, was the principle of lateral overflows entirely dropped, and it is now proposed to do away, little by little, with existing overflows.

The system of river improvement, which, from 1850 to the present time, has been carried out vigorously on all rivers, is founded on this improvement of the current-courses. The application of this principle, which is still considered by all experts to be the correct, decisive expedient for river improvement, infused new life into Dutch hydraulics about the middle of the preceding century, and has been forcibly maintained up to the present day in order to attain the desired end.

The general plan of action since 1850, at first applied to the summer bed only, afterward as far as possible to the winter bed, has been to give to every river a course of its own, without lateral overflows and with one continuous bed, not divided by islands or shoals. The rivers should be able to discharge as easily during winter as during summer water levels. For the safe discharge of flood-flows and ice, proposed lateral overflow had to be excluded, as far as possible.

In attaining a safe discharge, the demands of navigation also had to be considered. The division of the Rhine water which had been established at the Conventions of 1745 and 1771, was taken as the basis of execution of the works proposed in 1850. The permanency of the proportions in which each river branch discharges its portions of the Upper Rhine (which even then had existed for almost a century) showed that one could safely keep the proportions at $\frac{6}{9}$, $\frac{2}{9}$ and $\frac{1}{9}$, respectively, for the Waal, Lower Rhine and Yssel, in making projects for improvement in each of these branches.

Further, temporary normal widths at average water level or average summer water level, were proposed for all rivers, with the expectation, after further investigation, of confining them by degrees within these limits.

Important works for the improvement of Dutch rivers were undertaken, and quite or partly completed on this principle during the latter half of the century, and especially during the last decade.

Among these are: First, the improvement of the river mouths, which is nearly completed; secondly, the improvement of the river beds, by removing all that impeded the discharge of water and ice, and by normalization of the upper, as well as the lower, courses, which normalization is gradually approaching completion; and lastly, the raising and solidifying of the dikes, which has already been effected and to which a strong, fresh impulse was given by the normalization of the rivers. In contradistinction to proposals made before 1850, which were chiefly designed to avert the danger of breaks by ice-pack obstructions, the principle of river improvement, in 1850 and the following years, was designed to prevent as much as possible such obstructions by drift-ice. For the principal cause of the impairment of non-normalized, and, for the greater part, still unrestrained, rivers consisted in the deposit, through their irregular conditions, of sand and mud in those places where a continuous channel has to be kept clear for the unimpeded discharge of water and ice.

The history of ice-drifting in rivers shows that obstructions usually occur in places where there are shoals, stream divisions and bends which are too acute, and that most of the danger occurs when the outlets or mouths of the rivers are not free from ice, or have

not yet discharged it, and when in a strong thaw the ice from above comes drifting down rapidly.

Up to the present time it has been quite out of the reach of human power to prevent the freezing of the river, during a severe frost, and the breaking up of the ice after the thaw has set in, but the chance that the drifting ice—which is not only floating on the surface, but with which the greater part of the river is filled—will come to rest somewhere, is diminished considerably by the improvements carried out in the last half century, while these improvements at the same time promote the loosening of the river.

The raising and solidification of dikes, executed since 1850, has also been an important factor. For, as the dikes are higher, they will be able to check the water longer, and therefore the chance that the obstruction of ice will be removed by water pressure, before overflowing is greater, and, as a result of this, no failure of the dikes can take place. With freshet flows in the upper course, without ice, the danger of breaks, in general, is not great, as most of the dikes are high and strong enough at present to turn away high-water flows in open rivers; at least, as long as the river does not rise much higher than to the exceedingly high levels which have occurred in former years.

Overflows and lateral discharges cannot prevent the dangers of ice-drifting, but can only transpose them, and so have been condemned. This is the case because overflows, though they are not the cause of the formation of ice dams which sometimes are due to the irregular current, at all events render the removal of drift ice impossible by decreasing the pressure of the water, accumulated by ice obstructions.

But the improvement of the river mouths and the normalization of the upper and lower courses, by which the river bed has been brought into a regular state, and also the solidification and raising of the dikes, which are thus enabled to break flood flows, have all answered the purpose excellently, so that at present in addition to improvement in the interests of navigation, the danger of ice stoppages and dike failures has grown much less.

The improvement of the river mouths, as well as the normalization of the upper and lower courses of the rivers, has taught clearly that the profile to be made cannot be acquired by scour alone, but has to be attained almost entirely by artificial means.

Though at first the chief object was the improvement of the river bed, the interests of navigation soon became comparatively prominent. The formation of a continuous and sufficiently deep navigation channel in the rivers could not have been attained, however, by the application of the above-mentioned principles.

In order to accomplish this the principles of Mr. Fargue have been practiced since 1889; but it has not been possible by this method to attain the desired result. Accordingly, in the last decade it has proved desirable to confine not only the width, but, where necessary, also the depth of upper, as well as of lower, courses by the construction of ground-weirs or lower groynes, in order to attain a more regular and continuous channel of sufficient, and if possible, of constant depth. The results attained with these ground-weirs thus far, may be considered very favorable, especially for the lower courses. On the Waal, the result cannot yet be considered satisfactory.

The depths of the beds of the different rivers are now distinguished either by stability or by periodical variability:

First.—With constant or stable depth of the river bottom, we further distinguish:

a.—The regularly continuous navigation channel of sufficient depth, if in connection with the properties or nature of the material carried along, the width, the depth and the direction of the river bed are conformable to the regimen of the river; or, also, if the influence of the tides may be considered favorable; so that a quantity of sand or gravel, equal to the quantity received, is discharged regularly along the river bed or channel (Upper Rhine, Lower Rhine and Lek, Waterway to Rotterdam, Old Maas, Dordsche Kil);

b.—The formation of local shoals or bars in the navigation channel, if there is not yet a sufficient conformity between width, depth and direction of the river bed and the regimen of the river, in connection with the nature of the material moving onward along the river bottom. (The upper part of the Waal, the river stretches of the Dutch Upper Meuse, the Lower Rhine, Lek and Yssel, which are not yet sufficiently normalized.)

Second.—With "periodical variability" of the river bed we further distinguish:

a.—A fixed situation of the regularly continuous, navigable

channel of sufficient depth, but characterized by periodical shifts of the more or less deep places in the channel, which regularly change their positions, moving downward; (Merwedes);

b.—A periodical variability or downward change of places, as far as it concerns the situation of the channel as well as the depth of the bed, in which deep channels and shallow places of current changes move regularly down stream. (Lower course of the Waal.)

Further information about this will be given later on in this paper.

At present the general condition of Dutch rivers has, indeed, not become such as to preclude all danger from freshet flows and drifting ice, which, however, will very probably always exist to some degree; but this condition has been improved considerably; while, as useful fairways, these rivers also answer their purpose more and more fully.

A new mouth has been given to the Waal and Upper Merwede by the formation of the New Merwede, which has been completed and is now a powerful river, through which the regular discharge of ice is facilitated greatly. The Upper and Lower Merwede have become excellent fairways. The improvement of the New Merwede and the cut through the "Hoek van Holland" have been completed, so that the further improvement relates more exclusively to the navigation interests of the new waterway *via* Rotterdam to the sea, than to those of the river.

The delta of the Yssel was abandoned by shaping the "Keteldiep" into the principal mouth. The reopening of the "Oude Maasje," by which the Meuse, by the removal of its mouth to the Amer, will be separated from the Waal, with which, near Woudrichem, it unites with the Upper Merwede, is now nearly completed and will be opened soon. The Waal has been much improved by the numerous and important works of normalization. Islands have been connected with the banks and thus current divisions have been prevented, while the width of the summer bed, for the promotion of a continuous deep channel, has been greatly confined along almost the entire length of the river, so that the normalization, by this time, is nearly completed. The limitation of the width and depth by lower groynes is sought in various stretches of the Waal. On the Lower Rhine and the Lek, where it has also been necessary to confine the

normal width along almost the whole lengths of the rivers, several bad river stretches have been finally improved by normalization; some curves, impeding the discharge of ice, have been cut off, and shortly an important cut will be effected not far above Arnhem for cutting off a bend, especially troublesome to navigation.

The Yssel is all but normalized, and so is the Meuse below Venlo. The dikes along the rivers have been greatly improved, solidified and raised, and their tops which have now a minimum width of 4 m., with some exceptions along the left bank of the Waal, rise from about 1 to 2½ m. above even the highest comparative water level in an open river, known in this century.

The width of the most important dikes on soft bottom is more than 70 m. at the base. With good reason it may be declared that since 1850, and certainly in the last decade, the improvement of rivers has been highly important; even now, this improvement is being carried on continually, chiefly for the sake of navigation, so that it may be expected that this improvement, on the accepted system of normalization, will be ready within a space of time not too far removed; and in all rivers a regular continuous and sufficiently deep channel will be attained.

These works of improvement, and all that has been done, especially during the last decade, will now be considered somewhat more closely, in so far as they can be of interest.

The Improvement of the River Mouths.

Merwedes.—The formation and completion of the New Merwede, as the principal watercourse for the discharge of the water and ice of the Upper Merwede and also of the Waal and Upper Rhine, may be considered one of the most important river improvements.

The damming of the so-called "Killen" in the "Biesbosch" (which, being quickly obstructed by the breaking up of ice, became less and less fit for the discharge of high-water flows from the upper course) and the formation of a new and powerful river, the New Merwede, was undertaken soon after 1850, and has been completed.

The width of the summer bed is 450 m., at the upper mouth, at Werkendam, and increases regularly to almost 700 m. near the lower mouth on account of the strong influence of the tides.

At first it was thought possible to form the new river mainly by scour, but this was not possible, for, although a large part of the profile was formed by scour, this scouring was generally effected very slowly, and in some places where the river bed consisted of peat or clay no scour whatever occurred. The desired profile was formed by artificial means and chiefly by energetic dredging. The danger of breaks in the dikes of the Upper Merwede and Lower Waal, especially at the breaking up of the ice, has been diminished considerably by the formation of the New Merwede.

If this important river improvement had not been executed, the river itself, in course of time, would very probably have chosen a new course, which would certainly have caused disasters. The formation of the New Merwede, 20.5 km. long, was accompanied by the normalization of the entire Upper Merwede, 9 km. long, and of the Old or Lower Merwede, 15 km. long, which has also been completed. The normal width of the Upper Merwede, formerly fixed at 600 m., was reduced to about 450 m. at the upper mouth, steadily increasing to 500 m. at the lower mouth.

The Lower Merwede, particularly important as a fairway, was given a normal width of 200 m., along its entire length. In both these rivers, vigorous dredging has also been carried on. For establishing the channel, lower groynes have been constructed for several kilometers on the convex side of the banks, along the upper part of the New Merwede and the entire left bank of the Upper Merwede (Fig. 2); these lower groynes consist of rubbish dams, covered with gravel, 6 m. wide, and 0.80 m. deep, reaching to 3 m. below comparative low-water level, the bases, with a width of at least 25 m., having first been brought to a height of 3.80 m. below that level, by raising the bottom or by dredging. The lower groynes in the New Merwede, where one part is attached to the bank and the other lies in a line with the ordinary groynes for a length of about 100 m. and at a distance of 150 to 250 m. apart, were constructed in 1900, 1901 and 1902. In the Upper Merwede, where the construction was begun in 1899 and the last lower groynes will be completed in 1904, their distance apart is about 250 m., and they reach nearly half way across the river. The lower groynes are very satisfactory in both the Merwedes. The continuous depth below comparative normal low-water level amounts to 3 m. for the New

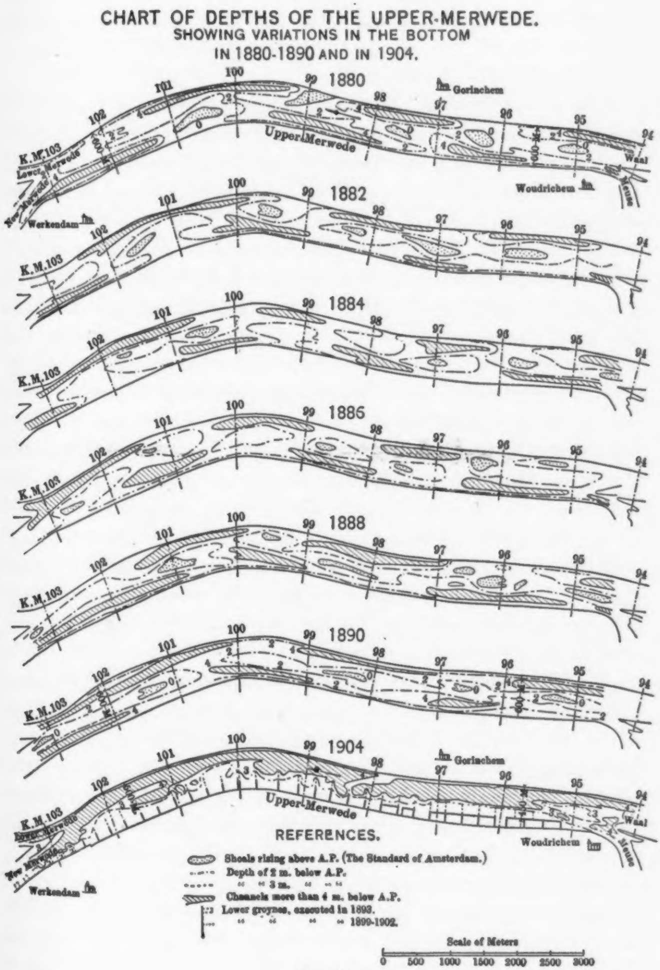


CHART OF DEPTHS OF THE UPPER-MERWEDE.
SHOWING VARIATIONS IN THE BOTTOM
IN 1880-1890 AND IN 1904.
1880
1882
1884
1886
1888
1890
1904
K.M.103
102
101
100
99
98
97
96
95
94
Gorinchem
Upper-Merwede
Lower Merwede
New Merwede
Werkendam
Woudrichem
Waal
Meuse
REFERENCES.
Shoals rising above A.P. (The Standard of Amsterdam.)
Depth of 2 m. below A.P.
" " 3 m. " " "
Channels more than 4 m. below A.P.
Lower groynes, executed in 1893.
" " " " 1899-1902.
Scale of Meters
0 500 1000 1500 2000 2500 3000

FIG. 2.

Merwede at present, while there is already a depth of more than 4 m. in the lower half of the river, where the locations of the channel are very constant. In the Upper, and also in the Lower Merwede, the channel depth amounts to 3 m. and more along a sufficient width of the channel.

Fig. 2 gives a clear illustration of the course of the current of the Upper Merwede, from 1880 to 1890, when the river still had a width of 600 m., and in 1904 with a width of from 450 to 500 m., and also after the construction of the lower groynes. From 1880 to 1890 the channels, at distances of from 2 500 to 3 000 m. apart, as shown by Fig. 2, with a depth of from 8 to 14 and even 18 m., alternated with shoals not more than 2 or 3 m. deep; these channels, winding through the river bed, were in regular zigzag lines, apparently subject to a definite law; in the middle of the stream there were shoals, rising 1 m. above A. P. (Amsterdam Datum).

It is characteristic of these rivers that in those profiles where change of current took place and where a minimum channel depth was found, the total area of the profile was a maximum. The downstream configuration of the bottom changed its place regularly. (See also description of the Waal.) This may be explained by the fact that, generally, the sand carried along by the river can settle more easily with a high-water level in the wide river stretches (current changes), than in the narrow river stretches (channels), while there is more occasion for scour in the channels; with low-water level, however, just the reverse takes place.

To this may be added that at the lower end of every channel the current divides into two parts, one of which follows the bank, while the other crosses the river bed almost at right angles, between two shoals, and again joins the water coming from a channel higher up on the opposite bank. So, every lower end of a channel was the starting point of a current division and every upper end the junction of two currents, and this is still so in the Waal.

The downward movement of the bottom, which changes periodically, is about 300 m. per year in the Upper Merwede; while in 8 or 10 years each channel occupied the place where formerly had been the channel lying immediately below it. This is the case in the New Merwede, where the shifting is 500 m. per year, with channel changes every 10 and 12 years, and in the Lower Merwede,

with a yearly shifting of about 300 m., and channel changes every 6 years. In the Lower Merwede, however, the location of the channel is fixed and only the depths are changeable; the greatest and least depths move down stream.

At regular distances in the channel of this river maximum and minimum depths are found, of which the distance apart remains constant during the down-stream movement. The condition of this river is favorable and the channel depth is maintained by the current itself.

The condition of the Upper Merwede, so much more favorable in 1904, as compared with former years, is immediately noticeable in Fig. 2. The continuous channel is near the right bank, and its depth is more regular, being almost always more than 4 m. and increasing to not more than 8 m. in only a few places. The condition in this continuous channel is now like that of the Lower Merwede which is explained above, and the New Merwede is being put in the same condition. The Merwedes answer their present purpose excellently. Besides discharging the water and ice, the New Merwede renders good service to navigation, while the Upper and Lower Merwede both offer excellent fairways.

The velocity of the current under present conditions is almost everywhere sufficient to prevent the formation of important shoals in the river bed. The width of the normal profile seems to be well chosen in comparison with the depth and the nature of the river bottom.

Since 1850 about 20 000 000 guilders have been expended for the three Merwedes, and more than 30 000 000 cu. m. of material have been removed artificially from these rivers.

New Waterway from Rotterdam to the Sea.—The purpose of the improvement of the lower part of the New Maas, or the so-called "Waterway from Rotterdam to the Sea," was the formation of a fairway, by which large sea-going vessels could ascend to Rotterdam from the sea without difficulty. It is true that while these works have resulted in great improvement in the discharge of floods and ice they were not undertaken to that end, for, such extensive works as have been carried out to attain the required depth in the interest of navigation, were not necessary for this purpose.

The investigation of the designs for the improvement of the

Waterway from Rotterdam to the Sea, in 1858, led to the opinion that the shortest and most natural route would be obtained by following the New Maas, and then the right branch of this river, called the "Scheur," from Rotterdam to the Isle of Rosenburg, and by damming the lower mouth of the Scheur; and, further, if the "Hoek van Holland" was cut through to get an outlet into the sea, north of the "Brielsche Gat," by two jetties, in order to obtain an open fairway, founded on the principle of the motion of ebb and flood tides in the lower courses of the rivers. The decision depended chiefly on the determination of the place of opening at the sea.

The quantity of water discharged from the upper course by the New Maas at average summer level is only 400 cu. m. per sec.

The construction of this new Waterway from Rotterdam to the Sea and cutting through the Hoek van Holland was resolved upon by the law of 1863. The river mouth was to be formed by two jetties, to be carried into the sea to a sufficient depth. These jetties were to be formed of low osier work, covered with heavy stone, and rammed through with oak piles.

The cut proper has a length of about 4 300 m. The north jetty is 2 000 m. and the south jetty 2 300 m. long. The ends of these jetties are now located on a line running almost parallel with the direction of the currents and the lines of great depth along the coast. At the shore end, the jetties are above storm-flood level, but at the sea end they are much lower.

As to the width of the waterway, this could not be settled theoretically, and it was necessary to make a temporary estimate. In the original project it was assumed that the waterway, for the greater part, would be formed by the operation of Nature, so that, after the construction of a channel at Hoek van Holland, 4.5 km. long, with a width of 50 m. and a depth of 3 m. below low water, the new river mouth would further form itself, to the desired dimensions, by means of the relatively small channel, through the influence of the ebb and flood, seconded by the drainage water. It was also hoped that the tidal current in the sea would prove to be sufficiently strong to carry away the outflowing sand, which would probably settle in front of the new mouth.

It has become evident, however, that this has been a miscalcula-

tion and that the scientific principle on which the project was based could not have good results until the river and the outlet were given the required dimensions artificially.

It is true that there was some scour in the cut, but not sufficient to form the desired profile, and, in time, the outflowing sand formed bars, both in and in front of the mouth, which were repeatedly counteracted by successively lengthening the jetties.

Considerable depth in the cut had been formed by scour, but the width was insufficient, while in the river mouth, where the width was fixed by the distance between the piers, the depth remained quite inadequate.

In 1881 a decree was issued for the resumption of the work, on the main principle of "artificial" construction for the tidal river. The normal width of the river to be formed in that way, was fixed at 250 m. at Krimpen, thence widening regularly to 340 m. at Rotterdam, and, further, to 685 m. at the sea end of the north jetty. As a basis for river improvement, it was decided that in the Waterway from Rotterdam to the Sea, a channel depth of 6.50 m. below comparative low-water level, for a width of at least 100 m., was to be formed. The works which have been carried out since 1881, have consisted in dredging the shoals in the river mouth; widening the cut; limiting the confluence of the rivers at the east point of Rosenburg; widening and normalizing the Scheur and the New Maas, by groynes and lower groynes, but chiefly by parallel weirs (lower groynes have been applied successfully from 1892 to the present time); and in the construction of works for bank protection.

The horizontal projection of the normalized banks consists of segments of circles and straight lines. The greatest depths are generally in the channel, where they would naturally be found according to the form of the river.

Including the improvement of the stretch of river between Rotterdam and Krimpen, 11 km. long, 25 000 000 guilders were expended from 1881 to the end of 1903, exclusive of the cost of repairs, which makes, since the commencement of the work, a total of 40 000 000 guilders.

The quantity of material removed between Krimpen and the sea, calculated in profile, amounted to 14 000 000 cu. m. up to 1881, and 51 000 000 cu. m. from 1881 to 1904.

The length of the Waterway between Rotterdam and the Sea is 33 km. The difference between ordinary, daily high and low water is 1.7 m. at Hoek van Holland, and 1.3 m. at Rotterdam. The depth, assumed in 1880 to be attainable, at average comparative high water, was fixed at 8.2 m. at Hoek van Holland, and 7.8 m. at Rotterdam, equal to a depth of 6.5 m. below normal, comparative low-water level. The condition has become much more favorable, however, the present demand being for a continuous depth of 7.5 m., below normal, comparative low-water level, in the waterway as far as Rotterdam, and 8.5 m. in the river mouth.

At present this demand is attained tolerably well along a channel width of from 100 to 150 m., except near Maassluis, where the channel depth is not thought to be quite sufficient. In the last decade, however, shoals were continually found, notwithstanding repeated vigorous dredging: First, just above Maassluis in the "Vergulde Hand;" second, near Maassluis; third, just below Maassluis in "den Hoorn;" and, fourth, further down in "'t Zuiden;" but these shoals were counteracted by lower groynes.

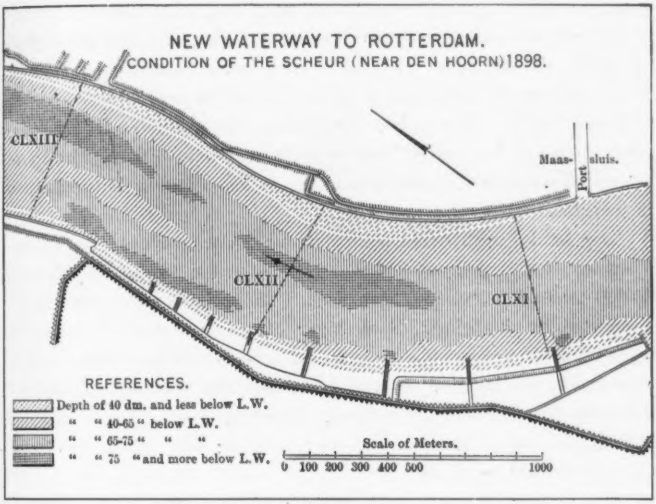
The shoal in the "Vergulde Hand" has, however, entirely disappeared since the dredging of a clay bank which was found there.

It is expected that the unfavorable condition near Maassluis will be bettered during 1904 by the construction of eight lower groynes, or low weirs, on the right bank, as was done on the left bank in 1901 and 1903.

The shoal in "den Hoorn" no longer exists, since the ebb and flood channels have been combined by building, in 1899, 1901-02, seven lower groynes which project from the left bank, and by which the channel depth was increased from 6 to 8 m. below low-water level. These channels were separated before by a bar (Fig. 3).

The shoal at "'t Zuiden" has been brought to a condition sufficiently favorable since the construction of thirty lower groynes which were used in the new waterway in 1892 for the first time. This construction has been continued during the succeeding years. There are now forty-four lower groynes all at right angles with the direction of the current, and eight others are being constructed during 1904 near Maassluis.

The length of the lower groynes has been fixed in accordance with a set of additional normal lines which bound the channel for


NEW WATERWAY TO ROTTERDAM.
CONDITION OF THE SCHEUR (NEAR DEN HOORN) 1898.
CLXIII
CLXII
CLXI
Maas-
Port
sluis.
REFERENCES.
Depth of 40 dm. and less below L.W.
" " 40-65 " below L.W.
" " 65-75 " " "
" " 75 " and more below L.W.
Scale of Meters.
0 100 200 300 400 500 1000

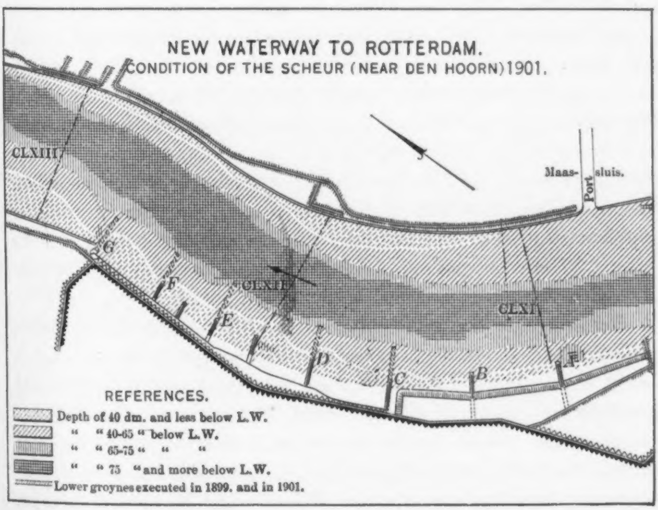

NEW WATERWAY TO ROTTERDAM.
CONDITION OF THE SCHEUR (NEAR DEN HOORN) 1901.
CLXIII
CLXII
CLXI
Maas-
Port
sluis.
G
F
E
D
C
B
A
REFERENCES.
Depth of 40 dm. and less below L.W.
" " 40-65 " below L.W.
" " 65-75 " " "
" " 75 " and more below L.W.
Lower groynes executed in 1899. and in 1901.

FIG. 3.

deep-draft navigation to a width of 300 m. The lower groynes are constructed as they are wanted, and consist of mattresses of fascine work composed of osier twigs covered with stone, and a great deal of sand. At the point they are 4 m. below comparative low-water level, and rise to landward to connect with the common groynes or with the bank, to 2 m. below comparative low-water level. The distance between the lower groynes is from 150 to 300 m. In those places where this distance proves to be too great a lower groyne is inserted.

The total length of these forty-four lower groynes amounts to 6 500 m., for which 280 000 sq. m. of fascine work, loaded with 60 000 tons of stone have been used. These dams were continually supported by dredging. Each layer of fascine work was covered with sand for which 840 000 cu. m. of dredged material was needed. Since the construction of the lower groynes a total amount of 2 500 000 cu. m. has been dredged. The total cost of this dredging, the sinking of mattresses and the covering with stone has been about 1 000 000 guilders.

The results attained with these lower groynes may generally be considered very satisfactory. In those places where they have been constructed, the continuous channel depth has increased 2 m. and more.

In the waterway proper, a yearly dredging of only a few hundred thousand cubic meters may be thought sufficient and the channel may be called very constant.

The yearly cost of repairs of all the foregoing works, including the dredging operations for maintenance, amounts to 450 000 guilders at present and this may also be calculated upon for the future. The construction of the Rotterdam waterway may be considered to have been crowned with success.

Rotterdam is the principal port for the exportation of Dutch products and its traffic is growing continually, while the transit trade with Germany keeps up an important Rhine traffic and promotes an extensive railway traffic. Of the incoming and outgoing vessels through the new waterway in 1903, several had a draft of from to 8.0 to 8.6 m. The voyage from Rotterdam to the sea or *vice versa* lasts only a few hours. Even during the severest winters, navigation in the waterway has never been stopped. The growth

of traffic to and from the sea in the Rotterdam waterway since the opening of the cut through the Hoek van Holland may be seen from Table 1.

TABLE 1.

Years.	Steamers and sailing vessels (fishing boats excluded).	Net registered tonnage.
1880............	7 008	2 962 180
1890............	9 637	6 034 631
1900............	15 202	12 844 033
1903............	15 802	15 306 278

The Removal of the Mouth of the Meuse to the Amer.—According to the law of 1883, a new mouth, the Amer, is being given to the Meuse, beginning at Hedikhuizen; it is a work undertaken exclusively in the interest of water and ice discharge, care only being taken not to injure existing navigation interests.

The present condition, showing a confluence of the Meuse and the Waal to the Upper Merwede near Woudrichem, and besides, a lateral connection at flood flows between the Meuse and the Waal at St. Andries, is very awkward, for the Waal has a much more voluminous discharge than the Meuse. With the exception of very high and very low water levels, the capacity of the Meuse amounts to only one-ninth of that of the Waal.

According as the Upper Merwede, which, for the greater part, depends on the greater or less discharge of the Waal, is high, the level in the whole lower part of the Meuse is high, even if the discharge of the Meuse itself is small.

With the work, the total cost of which amounts to more than 25 000 000 guilders, a double purpose is designed, *viz.,* the general interest of the Meuse and Waal and the improvement of the hydrographical condition of the Province of Noord-Brabant.

Every river, as far as possible, should discharge its own water into the sea under all circumstances. This is the chief end of river improvement, which has received attention in the project for the separation of the Rivers Meuse and Waal, with the accompanying shift of the mouth of the Meuse to the Amer.

The construction of the new mouth of the Meuse will be accompanied by the damming or the raising entirely and drying of the places of lateral overflows in the dikes at Heerewaarden, a work which is being carried out and which will shortly be finished, and by which the Meuse and Waal will then be completely separated from each other. The lateral overflow at Heerewaarden, of the Waal to the Meuse, where the difference of water level during floods in the Waal often amounts to 2 or 3 m., gave rise to a decrease of velocity in the Waal, below the place of overflow, while in the Meuse there was also a decrease of velocity because of the pushing up stream of water in this river. Further, the "Heerewaarden overflow" was a source of danger from drifting ice for the dikes of the Waal as well as for those of the Meuse.

The new river, the Amer included, has a length of 35 km. For a distance of almost 22 km., from the Heleinde to Keizersveer, the entire profile of the river had to be formed artificially. The summer bed of the new river, as well as of the Amer, increases in width and depth down stream, as they are subject to the influence of ebb and flood. The present River Meuse, between Hedikhuizen and Woudrichem, will be dammed by dikes in two places, at Heleinde and lower down at Andel. All works have now been completed so far that the opening of the new river, the works for which are now being carried out, will take place during 1904. It is not to be expected that the disturbed equilibrium in the condition of the river, above the new river stretch, will be perfectly restored at once. Thanks to the lowering of the water level, it will be possible to do away with other lateral overflows of the Meuse, if necessary, as at Beers, Bokhoven, etc.

The Normalization of Rivers.

Every Dutch river is distinguished by a summer and a winter bed. The summer bed is that part of the river bed which continually, that is, at low and at average water levels, discharges river water. It is the most active part of the river bed, and is composed of gravel and sand, which become finer as the mouth of the river is approached, and, at varying water level, are carried along the bottom by the stream, or are deposited.

The winter bed, on the contrary, which is elevated above the

summer bed to a height of a few meters, and is bounded by dikes or higher grounds, only discharges at very high water level, usually in the winter months, so that this part of the river bed is dry during the greater part of the year. Accordingly, the winter bed, which hardly changes, in the course of time consists of a solid, usually grass-grown clay soil, on which by inundations mud is very slowly deposited.

As long as the river is in a natural condition and not yet normalized, or its banks protected artificially, the summer bed is subject to continual change in its course, in consequence of natural modifications in its bends, made by the washing out of concave banks by the current and the filling of convex banks with sand.

The purpose of normalization is to improve the irregular course of a river. As has been stated already, the systematic works of normalization in Dutch rivers, though carried out on a modest scale at first, date from 1850 only.

The system is founded on the improvement of the current-courses. The works necessary for this consisted in:

Restricting the width, which is almost everywhere too great;

Connecting the islands or shoals with the bank, to do away with existing current divisions;

Deepening the river bed artificially in those places where the nature of the bottom is such as to render scour ineffectual, and consequently prevent the formation of a regular river bed;

Protecting banks in those places where a disadvantageous change of course might be expected to wash them out;

Lopping off windings, for the local improvement of the course;

Removing harmful works and opposing the construction of such works by private persons.

Thus the improvement or normalization of the river consists in changing the irregular form and course of the river bed into a more regular or normal form or course, as regards its width as well as its direction.

In order to attain this, normal widths of river beds at average summer water level were proposed from the very beginning for all rivers. Lowering the high-water level is only possible by a widening of the winter bed. By normalization of the rivers the

high-water levels are not lowered generally, because this normalization, as a rule, aims to restrict the profile, and seldom to widen it. The normal widths of the rivers, of the summer bed as well as of the winter bed, were revised and established by the Government in 1867. Greater knowledge of various river conditions, however, caused this general determination of the normal widths, together with the direction of the normal lines, to be modified considerably. For, the first determination of the normal widths took place at a time when the irregular, even wild, condition of the rivers required a cautious and slow normalization.

Moreover, the observations necessary to fix the most desirable or the utmost restriction of the river were wanting.

Thus normal width and direction of the standard lines demanded urgent revision in the course of years, as a right and rational normalization can be further projected and determined, only after a thorough study and increased knowledge of the regimen of the river.

Formerly, engineers acted by estimation, simply through want of sufficient knowledge, after they had accounted in some degree for the demands to which every river might be put, by observations in some river stretches which were in good condition for a short distance. Thus it is not necessary to state that at the time they did not know the influence which the fixed standard lines, after the partial completion of numerous works, would exercise, both on the desirable and continuous depth of the channel, and on the discharge of water and ice. As to the normal widths, almost all rivers have undergone a more or less important limitation and modification in their direction, especially during the last fifteen years, in order to attain the desired continuous depth in the channel.

This limitation was generally accompanied by energetic dredging for the purpose of:

Hastening the formation of a continuous channel;

Preventing the removal of the masses of sand below the place where the works were constructed;

Enlarging the profile, where the groynes had made it too narrow; and

Removing the masses of sand, continually carried down from the upper courses, together with the sand from local shifting.

The demand that in the river bed there shall be one continuous channel can be more easily answered by uniform width, in winding than in straight river stretches, that is, in winding river stretches, the current will run more toward the concave than toward the convex bank, and the channel will form along the concave bank. In straight river stretches, however, there is no reason for the current to run more toward one bank than toward the other, so that the channel, forming there, may run irregularly through the river bed, especially in rivers where the width is relatively very great, in comparison with the depth. In short and straight river stretches, however, it is not at all impossible for the profile of the rivers to show very regular form, with even depth along the entire width, and this is especially the case when it forms the connection between two other stretches curved in opposite directions. The depth in the straight or connecting part will then be less than that of the channel above and below, or in the concave bends; provided the river is of equal width everywhere. By giving to the straight or connecting parts a less width than that in the curved portions, it is possible to give more equality to the depths of the succeeding curved and connecting stretches. The normalization, with varying widths in the curved and connecting stretches, with which, according to the well-known system of Mr. Fargue, those widths gradually increase and decrease and pass imperceptibly into each other by small bends, so that the greatest normal width is found in places of sharp curvature, has also been applied to various Dutch rivers. In general it may be observed that, where the rivers or river stretches have a nearly constant, and not a periodically varying, bottom, the rules given by Mr. Fargue have been confirmed; while the deviations from them must often be ascribed to the lack of harmony between bends and widths, and the regimen of the rivers.

The places of greatest depth generally correspond to those of greatest curvature, and are found a little below them; the places where the current crosses to the other side are in the main the shallowest places in the channel. The great number of irregularities in the various river stretches, however, renders the determination of a fixed relation between curvature and depth impossible as yet.

Long, straight river stretches, bends with acute curvature and

stretches with gentle curvature, situated between rather greatly curved stretches having continuous curvature in the same direction, should be avoided as much as possible.

The purpose of normalization should be: attaining and maintaining, in a natural way, a regularly continuous channel of sufficient and even depth, and of sufficient width, through which the material (sand and gravel) flowing down or moving continually along the river bottom, will be discharged regularly in the same degree as it is carried along from above, without the formation of bars. The normal width of the summer bed should correspond to the regimen of the river and the nature of the river bottom, so that local scour and deposit in the channel are prevented. Generally, the narrowing of the summer bed of a river should only be effected when absolutely necessary, for, according to the great difference between the discharge of water in the various seasons, a narrow and deep river is subject to greater change of water level, than a wider river, and, consequently, there are greater changes of velocity, accompanied by scour or deposit of solid matter in the channel. If the gradient and profile of a river are invariable, with an even motion of the water, the raising or lowering of the water levels, with equal increase or decrease of discharge, will be directly proportional to the depths, or inversely proportional to the $\frac{2}{3}$-power of the widths, for two rivers with equal gradients and discharges but with different widths and depths; while, further, with equal gradient and discharge, the area of the profile will be less and consequently the velocity greater for the river with the greater depth or less width, as, with even motion, the product of the second power of the area of the profile and the average depth may be considered invariable.

The restriction of the river to the normal width is effected by groynes or parallel weirs. At the concave side of very sudden or sharp bends, parallel weirs are generally preferred. With restriction of the river by groynes, which have been used in Dutch rivers more frequently than parallel weirs, perpendicular groynes, or those at right angles with the current, are usually constructed. Parallel weirs, being too expensive and not so well adapted to modification, have been constructed in smaller numbers than groynes. The distance between the groynes varies from 150 to 200 m. in the Waal, from 100 to 150 m. in the Lower Rhine and Lek and not more than 100 m. in the

Yssel. As the normalization is chiefly designed to increase the channel depth during low-water level, and as it is desirable not to confine the high-water level profile too much, the height of the groynes at the river end is usually fixed at the height of the average comparative summer water level, or a little higher, with a landward slope of from 100 or 200 to 1. Experience teaches that it is of great moment to give a gentle slope to the river ends of the groynes of about 4 to 1, down to the bottom of the river, and to protect the river bed from scour around the river ends of the groynes.

In some cases it may be necessary to confine the width, as well as to decrease the depth of the river. Such works of restriction, or lower groynes, are necessary, either to decrease the depth in a narrow, deep channel in an otherwise shallow river stretch, and to distribute the depth more regularly along the width, or to compel the channel to move more toward the opposite bank; a continuous set of lower groynes may also be used to make the gradient of the river more regular. Numerous lower groynes have been constructed in later years in the Waal, in the Upper and New Merwede and in the Rotterdam Waterway. In the Waal the result attained has not been satisfactory until now; in the other rivers, however, they have proved to be of much service. Until now it has not been thought necessary to construct ground weirs or low parallel works in the direction of the current, as these works are considered to be less efficacious. The groynes and parallel weirs are composed of osier twigs and sand, loaded with stone.

Upper Rhine and Waal.—The normal widths of this the most important of the Rhine branches, which were revised and established by the Government in 1867, amounted to 400 m. for the summer bed of the Upper Rhine, and 360 m. for the Waal as far as Zalt-Bommel, widening below it to 400 m., while the normal winter bed, including the summer bed, was fixed at a width of from 750 to 800 m. The normal width of the Upper Rhine was afterward decreased to 340 m. The average gradient of the Upper Rhine ranges from 0.00008 at low-water level, to 0.00011 at average water level, and 0.00017 at high-water level. The length of the Upper Rhine is 10 km. The average gradient of the Waal corresponds to this; it is greater with low-water and a little less with high-water level

than in the Upper Rhine. The length of the Waal is 84 km. For the discharge of the Upper Rhine the following quantities per second may be assumed: At highest level, more than 10 000 cu. m.; at average summer level, 2 150 cu. m.; and at normal low-water level (1.50 m. at Cologne), 1 200 cu. m.

For the discharge of the Waal, the following quantities per second may be assumed: At highest level, more than 6 000 cu. m.; at average summer level, 1 500 cu. m.; and at normal low-water level, 870 cu. m.

After the most irregular river stretches had been normalized during the first period, the normalization was completed according to established principles during the next period, from 1875 to 1889. In 1888 the summer bed of the river had the established width along its entire length; but, both in point of depth and direction, the condition of the river as a fairway could not be considered satisfactory. Impeding shoals, sharp bends or winding current changes were still obstacles to navigation.

For the Rhine below Cologne and, in the Netherlands, for the Waal, a channel depth of 3 m. at normal low-water level (1.50 m. by Cologne water mark) was thought necessary. In a few places, this depth below that water level (corresponding to about 1.25 m. below average summer level) required more than 1 m.

The result attained, therefore, gave rise to a revision of the normalization of the Waal, for which the demands of navigation were subjected to a new investigation. As a result of these investigations, in 1889 a project for the Waal improvement was completed and approved, by which a continuous channel depth of 2.70 m., if possible, afterward of 3 m., with the above-mentioned low-water level at Cologne, was to be attained. The channel width thought desirable for the Upper Rhine was 150 m., and for the Waal, 100 m.

Generally, the places where the required continuous depth is not yet established are in straight stretches and places of current change, where the average depth is almost the same as the depth found along the entire bottom width of the profile. While retaining the normal widths of 1867, a narrowing of from 360 to 310 m. was agreed upon above Hurwenen, not far from Zalt-Bommel, in the straight stretches and in the sinusoidal transition points, *viz.*, the points where the directions of the curves change, and widening

regularly below Hurwenen, where the influence of ebb and flood is perceptible, to 400 m. in the straight stretches. These widths increase more or less in the bends according to the curvature. For the standard or normal bank lines, lines of increasing and decreasing curvature (so-called lemniscates) were agreed upon according to Fargue. The restriction of the width was attained by lengthening the existing groynes perpendicularly to the standard lines; in those places where the distance between the groynes was too great, intermediate works were constructed (Fig. 4).

The works of improvement, projected in 1889 were carried out in four years. The masses of sand, dredged in this period from the normal bed of the Waal, almost 7 000 000 cu. m., were used to fill up stretches between the groynes, which fillings, after having been protected against washing out by osier works loaded with stone, promoted at the same time, the regular discharge of the river.

The normalization of the Waal was continued afterward, and it is now completed. The depth of 2.70 m. below normal low-water level is found almost continuously in this river, though it seems that its general condition is not yet satisfactory in every respect. It has not yet been determined as to whether or not it will be necessary in a few years to confine the normal widths of the Waal to a greater extent; for the time being, it will be necessary to resort to yearly dredging.

In order to diminish the undesirable windings of the channel in the slightly sinuous river, it will perhaps be necessary to modify the horizontal projection of the river somewhat so that it will become more winding and the gradient more gentle.

The yearly quantity of dredged material for the Waal is at present 350 000 cu. m. During the decade, 1894-1903, a total of about 5 500 000 cu. m. has been dredged from the river in order to maintain a sufficient depth, the cost having been 1 250 000 guilders.

The normal bank lines of the Waal consist of a succession of alternate curved and straight lines, the latter being tangent to the curved lines from either side. Real sinusoidal transition points between curves of opposite direction have not been planned for the Waal.

The number of straight river stretches ranges from six for the

part from Pannerden to Nymegen (16 km. long) to twenty for the part from Nymegen to Zalt-Bommel (50 km. long), and six for the part from Zalt-Bommel to Woudrichem (18 km. long), thirty-two in all. More than half of these straight stretches are less than 1 km. long; the others have lengths ranging from 1 to 2 km., except a straight stretch near Nymegen, which is about 2.5 km. long.

Generally, it cannot be said that long straight parts have channels inferior to the short, straight parts, which are much shorter than the bends. Yet a more sinuous course of the river along its entire length would probably be preferable for maintaining a continuous channel of sufficient depth without windings. There are five river stretches in the Waal, bounded by straight normal lines, to which, both above and below, curved river stretches with a curvature continued in the same direction are connected.

One of these stretches not far below Nymegen, at the so-called "Groenelanden," has always been one of the least efficient on the whole river, as regards the channel-depth; and the channel had to be given the desired depths repeatedly by vigorous dredging every year. It is intended to try and improve this by modifying the right summer standard line in that place, while, at the same time, the straight part will disappear. In a second river stretch shaped like the first and situated near Tiel, the normal width in the curves had also to be reduced continuously to the same width as in the straight parts in order to maintain the depth attained by dredging. Conditions have become quite satisfactory on this stretch in the last few years.

No particular remarks need be made about the remaining three of the five river stretches previously mentioned; they are not distinguished from others by less favorable conditions. As to the Upper Rhine, this completely normalized, but only short river, between the German frontier and the separation dam at Pannerden, is distinguished by a very regular river bed with a more than sufficient depth in the channel, which is everywhere at least 200 m. wide. The least depth in the channel of the Upper Rhine was 3.35 m. in 1903 during normal low-water level.

The sand coming from above is flowing down to the Waal very regularly in general in the river bed of the Upper Rhine, without forming shoals. In the Waal, which is much longer, the phenomenon

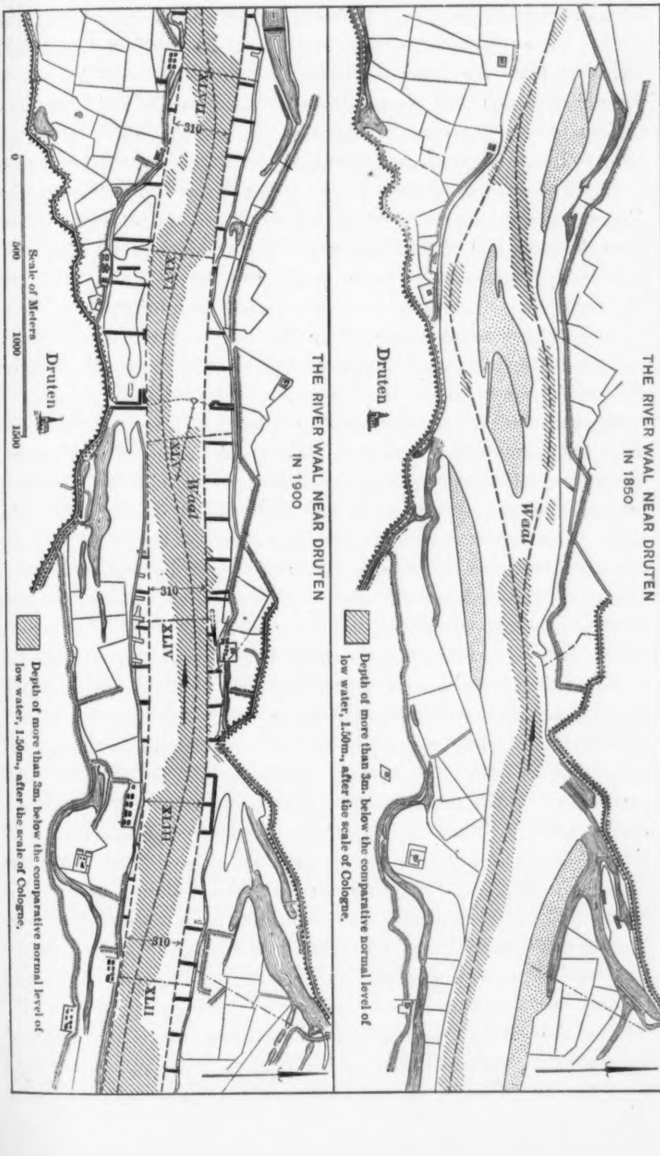

THE RIVER WAAL NEAR DRUTEN
IN 1900
Druten
Waal
XLVII
XLVI
XLV
XLIV
XLIII
XLII
310
Scale of Meters
0
500
1000
1500
Depth of more than 3m. below the comparative normal level of low water, 1.50m., after the scale of Cologne.
THE RIVER WAAL NEAR DRUTEN
IN 1850
Druten
Waal
Depth of more than 3m. below the comparative normal level of low water, 1.50m., after the scale of Cologne.

FIG. 4.

of sand shifting has quite a different aspect, and, in this respect, the Waal may be divided into two parts which are easily distinguished, *viz.,* that from the separation dam at Pannerden to 34 km. down stream, in which part the positions of the channels and shoals are subject to very little or no change at all, and the condition of the river bed may be considered invariable; and, further, the lower part of the Waal for a length of 50 km., as far as the confluence with the Meuse, in which part a general downward movement, both of the deep channels and of the shallow parts, may be observed distinctly, just as in the Upper Merwede, before the restriction of the width and depth by groynes and lower groynes had been effected.

The motion of the sand along the bed of the river seems to consist in a continual exchange of sand; for the shoals fill the upper ends of the channels, and the lower ends of the channels are scoured downward, so that the sand, flowing from these channels, can once more form shoals and sand bars. Thus, the masses of sand, taken together, are not in a continual and slow motion, but the individual grains, move some way down, and then subside for an indefinite time. This downward movement takes place in the Waal with an average velocity of from 250 to 500 m. a year and is independent of the form of the horizontal projection; that is to say, independent of the straight parts and curves and of the location of the channel at the convex or at the concave side. The works, begun in 1889 (to continue the normalization of the river), do not influence it either, as the phenomenon of sand shifting in the Waal has been noticed in exactly the same way, according to observations in the period from 1888 to 1893, as well as in that from 1893 to 1899, after the completion of the normalization works. It is probable that the phenomenon will obtain in the now normalized Waal, and it is also probable that it will not be possible to modify it, until the numerous unwished-for windings in the channel have been diminished by transforming the horizontal projection of the river, or by greater limitation of the width, just as in the Upper Merwede. In order to promote this, and to improve the required continuous channel depth permanently, by which the yearly dredging for maintaining the channel may also be diminished, the construction of lower groynes was commenced in the Waal in 1897 and has been continued in the following years. The lower groynes are at right angles

to the normal bank lines, and extend to 100 m., at the most, from this line into the river; in those places where there are common groynes, the lower groynes are made in a line with them. Their distance apart is about 200 m. The inner half of these is formed of fascine work, covered with shingle, with a crown 13 m. wide, and slopes of 1½ to 1; the outer half is formed only of gravel, to a width of 5 m. at the crown. The tops of the lower groynes are 3 m. below normal low water. Wherever the river bottom is deep, in places where the lower groynes are to be made, this bottom, under the groyne, is raised with gravel to a height of 4.6 m. below normal low water, for a width of 20 m.

At the end of 1903, ninety-two lower groynes had been constructed. These were distributed along various river stretches; five above Nymegen, eighty-four between Nymegen and Zalt-Bommel and three lower down. The cost of the construction of these lower groynes was 364 000 guilders. The results attained with them in the Waal cannot yet be called satisfactory in all respects, as the numerous windings of the channel have not yet been permanently curbed. Part of this is probably due to the distance between the groynes being too great, causing great depths between them, and this distance will be decreased by interposing lower groynes. It is desirable to make the channel of more regular curvature, as much as possible, by means of these lower groynes, and at the same time create a lighter gradient, for which these works will contribute in some degree. The total cost of the construction and improvement and of the ordinary repairs for the Waal amounted to 12 500 000 guilders.

The traffic in the Waal has been almost doubled during the past decade.

Rannerden Canal, Lower Rhine and Lek.

It was not until 1850 that a new period of normalization opened for this branch of the Rhine, on the before-mentioned principle of the formation of one continuous current-course of definite width without excessively acute bends.

The normal widths of the summer bed, established in 1867, were modified in 1892 for the river above Vreeswyk, where the influence of the tides is still perceptible, because it was proved that the depth

of 2 m. below normal low-water level, required for navigation, could not be obtained without further restriction. Not only the width, but also the direction of the normal lines, has had to be revised considerably, but by degrees. Straight stretches have been avoided, as much as possible, and the bends have been formed with lines of increasing and decreasing curvature. The bends, to as great an extent as possible, have curvatures in opposite directions.

Narrowing at the transition points, as in the Waal, was thought unnecessary for this river, as a sufficiently deep and wide channel was generally found in the straight stretches, while in the bends the channel was winding.

The result of the normalization of the Lower Rhine and Lek has been satisfactory in every respect, and is comparatively more favorable than for the Waal. The number of transitional points, cr places of current change, in this river averages about one point to each 2 km. The demand for a channel depth of 2 m. below normal low water above Vreeswyk, and a width of 50 m. has been nearly answered. From Vreeswyk to Krimpen the depth required is about 2.50 m. below that water mark. A continuous depth of 2.50 m. is wanting in a few places only, while along the greater part the channel is deeper (Fig. 5).

The location of the channel and the depths of the bottom in the Lower Rhine and the Lek are both characterized by great stability.

The total cost for the construction and improvement and for ordinary repair amounted to 10 500 000 guilders.

Yssel.

The condition of this branch of the Rhine corresponds nearly to that of the Lower Rhine; but the discharge and the channel depth are less.

On account of the "Waterway from Zwolle to Sea," in the first place, the improvement of the Lower Yssel and of the present mouth of the river, called the "Ketel," has been carried out.

The purpose of these works was to attain a channel depth of 3 m. This depth is now found in that part of the river, and was acquired by restricting the width and by dredging and excavating, accompanied by partially damming the other mouths of the Yssel, only the

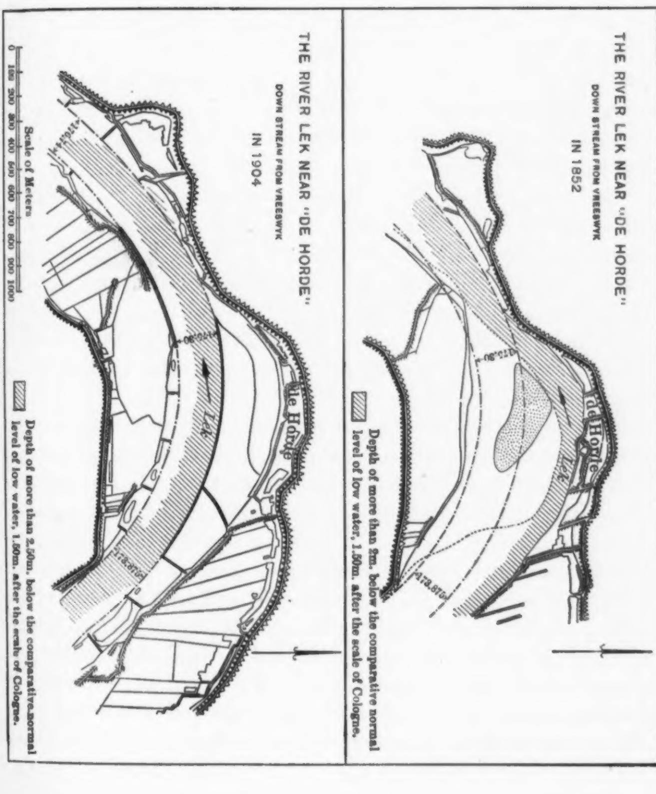

THE RIVER LEK NEAR "DE HORDE"
DOWN STREAM FROM VREESWYK
IN 1852
de Horde
Lek
173,80
173,979
Depth of more than 2m. below the comparative normal level of low water, 1.50m. after the scale of Cologne.
THE RIVER LEK NEAR "DE HORDE"
DOWN STREAM FROM VREESWYK
IN 1904
de Horde
Lek
173,80
Scale of Meters
0 100 200 300 400 500 600 700 800 900 1000
Depth of more than 2.50m. below the comparative normal level of low water, 1.50m. after the scale of Cologne.

Fig. 5.

"Keteldiep" being maintained as the mouth of the Yssel. The required depth is maintained by the current. The normalization of the Upper Yssel also, is nearly completed. The channel is fixed. The remaining parts of this river require no further remarks.

Meuse or Upper Meuse.

The Meuse is governed chiefly by meteorological conditions. The small discharge in summer, in connection with the river's having gradient in France, Belgium and to a great extent in the Netherlands, is the reason that very little or no depth is to be found in the channel during low water. In France and in Belgium the Meuse was canalized by numerous weirs with locks.

In Dutch territory, from Eysden to Woudrichem, the Meuse or Upper Meuse has a total length of about 265 km. with a fall of about 50 m. Above Venlo the gradient is 0.0004, decreasing downward to 0.0002; below Venlo, and as far as Hedel, where the influence of the tides is still perceptible, it is only 0.00006; while the average gradient of the other rivers in the Netherlands is about 0.00011. The discharge of the Meuse, with normal low-water level, is about 80 cu. m. per sec. at Venlo.

This river is subject to rapid and powerful rises and falls. The rise differs considerably in various parts, in the Province of Limburg, and is closely connected, not only with the gradient, but also with the varying height of the banks, which for a great extent are overflowed during high water. The lowering of these high-water flows is only possible by lowering these banks, more or less, and, accordingly, widening the winter bed. The proportion between the least and greatest discharges is 1:90, while for the Waal this proportion is 1:10, and for the Upper Rhine 1:13. Yet the channel in the Meuse is characterized by stability, so that periodical variability of the river bottom is not noticed. Above Venlo the river is full of shoals, and these, after removal, form again in the same places during the next flood flow.

The systematic normalization of the Meuse also dates from 1850. Below Venlo the river has been normalized, especially in the last decade, for the purpose of forming a useful fairway as well as promoting a regular discharge of floods and ice from the upper course. This normalization has been nearly completed. It becomes

evident, however, that, only by considerable restriction of the normal widths, agreed upon in 1867, can a sufficiently deep channel for the summer bed be maintained. The Fargue system was applied. In several stretches the required channel depth could not be maintained, except by restricting the bends, also, to the same width as at the transition points. This width is 95 m. between Venlo and St. Andries, and widens to 160 m. at Hedikhuizen, where the new river begins.

The groynes and parallel dams in the Meuse are brought to a height of 1.20 m. above the average comparative summer level. The average number of transition points, or places of current change, is as follows:

Between Tegelen and Mook (length, 62 km.) 1 point in 1.6 km.; between Mook and St. Andries (length, 60 km.) 1 point in 2 km.

The river above Venlo and Roermond is to be made navigable by canalization only, on account of the shallow channel depth, steep gradient, small discharge in summer and great discharge in winter.

Conclusions.

According to the preceding statements, the river improvements, which are carried out with a view to promoting the interests of water and ice discharge, as well as for navigation, have been characterized in the last decade by the principles which lead to conclusions as follows:

The system, based on the improvement of the channels, and since 1850 applied to Dutch rivers, has been maintained for the general improvement of the rivers.

This general improvement, consisting chiefly in: the improvement of the mouths of the rivers, normalization of the upper and lower courses, dispensing with lateral overflows and improvement of the dikes, was continually and vigorously prosecuted, and has been nearly completed.

The formation of a regularly continuous channel of a sufficient and even depth, which depth can preserve itself in a natural way, so that the matter continuously carried down from above may be discharged in a regular way and in the same measure, was furthered principally by restriction of the width of the summer bed; by normalization works, principally by groynes located a little above

the average summer level; accompanied by energetic dredging. The normal width of the summer bed had to be conformable to the regimen of the river and the nature of the river bottom, so that local scour and deposit in the channel are out of the question.

In order to be able to effect the required channel depth, which had not yet been attained, Mr. Fargue's principles of river improvement have been applied since 1889, in so far as they could be made to agree with existing conditions.

In general, the rules laid down by Mr. Fargue with respect to rivers have proved correct. The deviations from them are generally to be ascribed to the insufficient horizontal development of some of the river stretches, to bends succeeding each other in an unsuitable manner, or to insufficient correspondence between bends and widths with the regimen of the river.

The condition of Dutch rivers, does not show that with a suitable width of the summer bed a river ought to be decidedly winding in order to preserve a regular and even depth; thus in straight river stretches a regular channel of sufficient depth may be found. Suitable bends, however, have the advantage that, with equal channel depths, the width in the bends can be greater, and the channel will take a definite and more settled place, without undesirable windings, which is usually not the case in a comparatively long river having, in general, a very slightly sinuous form.

Giving the greater part of the summer bed of a long river a gently sinuous form, by normalization works, will lead inevitably to its undesirable, increased, and continuous restriction, on account of the increasing gradient and consequently the increasing velocity, in order to attain, not only an invariable location, but also a sufficient depth of the channel during low water.

However, it is desirable not to confine the width more than is absolutely necessary along a great length of the river, on account of the smaller cost of normalization, also, on account of the discharge with a rising water level; because, under the same circumstances with respect to discharge and gradient, a wide river shows a greater increase of profile and consequently is subject to less strong change of water level and therefore of velocity than a narrow and deeper river. For that reason, a rationally winding river will generally be preferable to a river having a very slightly sinuous form.

However, a greater restriction may prove to be necessary, in view of the existing state of things, in order to complete the insufficiently normalized stretches, to check unwished-for windings of the channel, or to arrest periodical variability of the river bottom, with the downward movement of the alternate deep channels and shoal places where the current changes. By this a regular, continuous and sufficiently deep channel will be attained, either with invariable depth or with a regular downward movement of the maximum and minimum depths in the channel, according to the regimen of the river in connection with the character of the river bottom and the material carried by the water.

To this end it has proved desirable to confine in some upper and lower courses, not only the width, but also the depth of the river bed by lower groynes, the crown of which is placed about 3 or 4 m. below the normal comparative low-water level. The results attained thus far with these lower groynes may be considered favorable in the Upper and New Merwede, but less satisfactory in the Waal; it is expected that there, also, by decreasing the distance between the groynes, their efficiency will not fail to manifest itself in the long run.

The construction of the lower groynes is intended not only to restrict the width, but also to restrict local excessive depth in the summer bed, so that the continuous depth will be distributed more regularly throughout a greater width of the river bottom, often accompanied by a transposition of the channel, in order to procure a more permanent location for the channel; in a river of more or less gently sinuous form, as the Waal, it deserves recommendation to give a greater efficacious curvature to the channel, if possible, by the construction of lower groynes, at the same time promoting a regular and smaller gradient. In tidal rivers it would seem desirable to join the flood and ebb channels, which may be separated from each other locally by a bar, by the construction of lower groynes, as applied with good results in the Rotterdam waterway.

The construction of low parallel works, or of ground-dams, in the same direction as the current, has been thought less expedient, so that, until now these works have not been applied.

Every improvement of a river mouth and every normalization of a river, as much as possible, should be accompanied by an artificial widening of the profile by dredging.

The lowering of flood flows can only be attained by efficacious widening of the winter bed, as the normalization of the rivers, as a rule, aims at the restriction, and very seldom at the widening of the profile.

River stretches like the upper part of the Meuse, in the Province of Limburg, which have a heavy gradient for a comparatively great length, accompanied by very light discharge during a great part of the year, and proportionally great discharge during the other part of the year, can only be rendered navigable by canalization.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 57.

NATURAL WATERWAYS.

ROLLING DAMS.

By K. E. Hilgard, M. Am. Soc. C. E.

The efforts tending toward the improvement of internal navigation and the utilization of water-power, in Germany, England and the United States, and especially in Switzerland, have offered many opportunities in recent years for the application of the Stoney type of roller sluice-gate.* Although such gates for individual openings in movable dams up to 80, 90 and even 100 ft. in width, for smaller heights, and of nearly 30 ft. in height, for smaller widths, were used successfully and are operated easily by counterbalance weights, and are proposed to be constructed of still larger dimensions in Europe as well as in the United States, a desire has frequently been felt for a device permitting the closing and opening of gaps of considerably larger proportions by means of one single body, in the shortest time possible, without requiring intermediate supports or trestle bents. The American bear-trap gate has been made to answer in some cases in the United States, as in the Chicago Drainage Canal.

* As first built by him in Ireland near Belleek and Ballinasloe, and, since then largely used on the Rivers Aare, Rhone and Rhine, in Switzerland, as well as for the regulating works on the Chicago Drainage Canal and the Sault Ste. Marie (Lake Superior) Water-Power Canal, and for many places in Great Britain and her colonies.

In Germany, within the past few years, an entirely novel construction has been rapidly gaining ground, and the purpose of this paper is to describe this device and show its adaptability under varying conditions. Besides the advantage of its applicability for very large openings and for rapid operation, this new type, the "rolling dam," does not ordinarily require a separate service-bridge to connect piers and abutments and to carry operating machinery, as the Stoney gates do; and this feature alone leads to a very considerable economy in first cost.

Two such "rolling dams," of riveted-steel construction, have been built, and the great satisfaction which they have given thus far has led to the adoption and consideration of this new type of movable dam for a number of very important regulating works on various rivers in Germany and Switzerland. The first of these dams was built at Schweinfurt, Bavaria, in the "Sau" branch of the River Main, which serves as a race-way for this latter. The local difficulties to be guarded against were the floods caused by the breaking up of ice gorges. In the main river an opening of 117 ft. 8 in. in width, and in the branch named an opening of 60 ft. in width had to be provided, possibly on very short notice, and each opening had to be closed by a single shutting body.

Fig. 6 shows the location of two rolling dams. Both these openings were formerly provided in part with Poirée needle dams, but their operation proved to be too slow for such emergencies as those mentioned. For the purpose of demonstrating the serviceability of the new type of movable dam, the smaller one, in the race-way, was built first, in 1901-02, and, upon its proving a success, the larger one was built in 1903. Fig. 1, Plate XXX, is a general view of the smaller dam, and Fig. 2, Plate XXX, shows more clearly the operating mechanism. The details of the construction are shown on Plate XXXI.

At the Internal Navigation Congress, at Dusseldorf, in 1902, to which the writer was delegated by the Swiss Federal Polytechnic Institute, a complete model of the smaller of these two dams was placed on exhibition, and was explained and manipulated by its originator and patentee, Mr. Max Carstanjen.* A description of the rolling dam appeared in the reports on this Congress.† A

* Chief Engineer of the Gustavsburg bridge works, near Mainz (branch of the Vereinigte Maschinenfabrik, Augsburg, und Maschinenbaugesellschaft, Nürnberg, A. G.

† Part I, Communication No. 10.

FIG. 1.—ROLLING DAM AT SCHWEINFURT.

FIG. 2.—MECHANISM OF ROLLING DAM AT SCHWEINFURT.

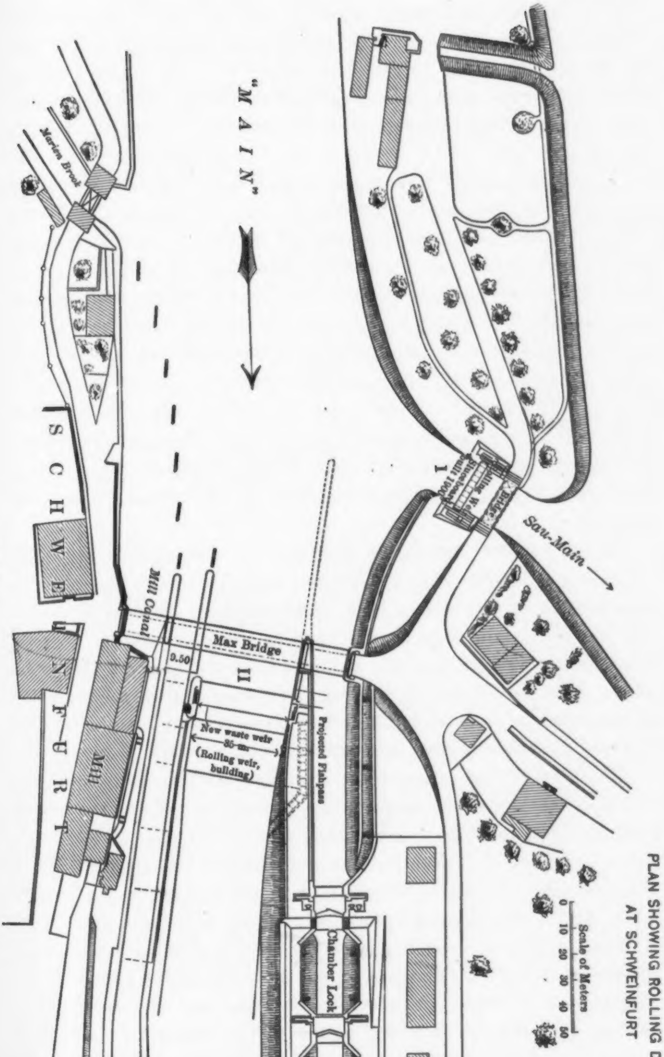

PLAN SHOWING ROLLING DAMS
AT SCHWEINFURT
Scale of Meters
0 10 20 30 40 50
"MAIN"
Marien Brook
SCHWEINFURT
Mill
Mill Canal
Max Bridge
0.50
II
New waste weir
35 m
(Rolling weir,
building)
Projected Fishpass
Chamber Lock
I
Bridge
Sau-Main

FIG. 6.

hollow, riveted, water-tight cylinder, not unlike a riveted steel-plate boiler, serves as a closure. Steel ropes, slung around the ends of the cylinder, serve to roll it up or let it down, like a barrel or large heavy tube upon an inclined plane. Large cog-wheels on the ends of the cylinder engage with the rack rails upon the inclined planes.

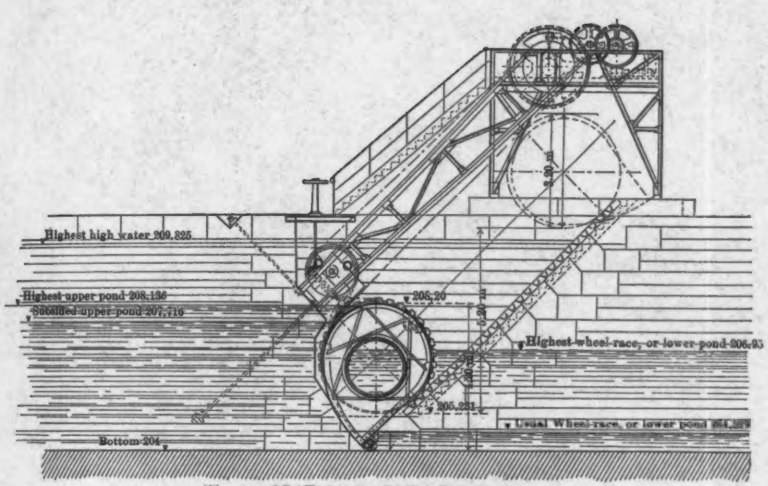
To effect a nearly water-tight closure with a hollow cylindrical body had been proposed previously at various times by Mr. Hirzel-Gysi, a Swiss engineer, by Baurath Hoech, formerly technical attaché of the German Legation at Washington; and also by Mr. Koechlin, a Swiss engineer in Paris; but by methods differing from those of Mr. Carstanjen, who not only proposed but carried out his original idea successfully. The writer's visit to both of these dams at Schweinfurt convinced him that there is no reason why openings of 150 ft. in width, and even more, and of a height of 30 ft., with a corresponding width, cannot be regulated successfully by a single cylindrical body; and, indeed, contracts are about to be entered into for the construction of rolling dams of the large dimensions named.

In the smaller opening at Schweinfurt, closing an opening 60 ft. wide and having a depth of water of 14 ft. in the race-way, the cross-section of the rolling body is pear-shaped, in order to reduce the buoyancy, and only at the ends is the cross-section circular. The closing, or cutting edge, as it were, of the dam, at that point of the cross-section which rests on the bottom sill in the race-way, is fitted with an oak timber, to which some pressure can be applied, whereby a satisfactorily tight contact with the sill is obtained.

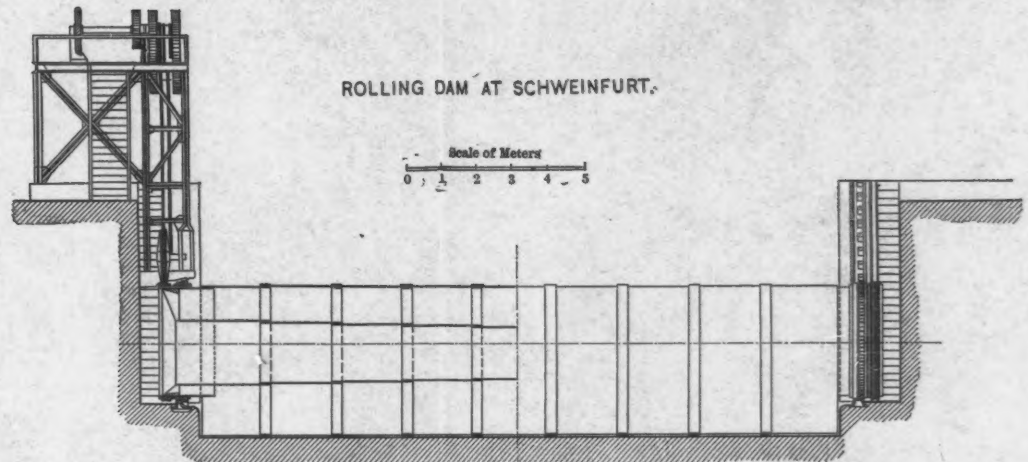
The area of the cross-section is dimensioned so that, in rolling up the dam, it always occupies the same space which the rolling body occupied previous to its motion, so that, not only no additional water has to be displaced, but the water assists the upward motion. For this same reason, no impediment to the motion, owing to sediment, debris, ice, floating bodies, or rubbish, is to be feared.

The steel ropes encircling each end of the cylinder are fastened thereto at one point, and are slung around a guide pulley and a winch drum as well. In principle the ropes may be considered as endless, but each end is wound on one of two separate drums which can be varied in their respective positions, so as to permit of taking out any slack in the rope. While, generally, only one end of the

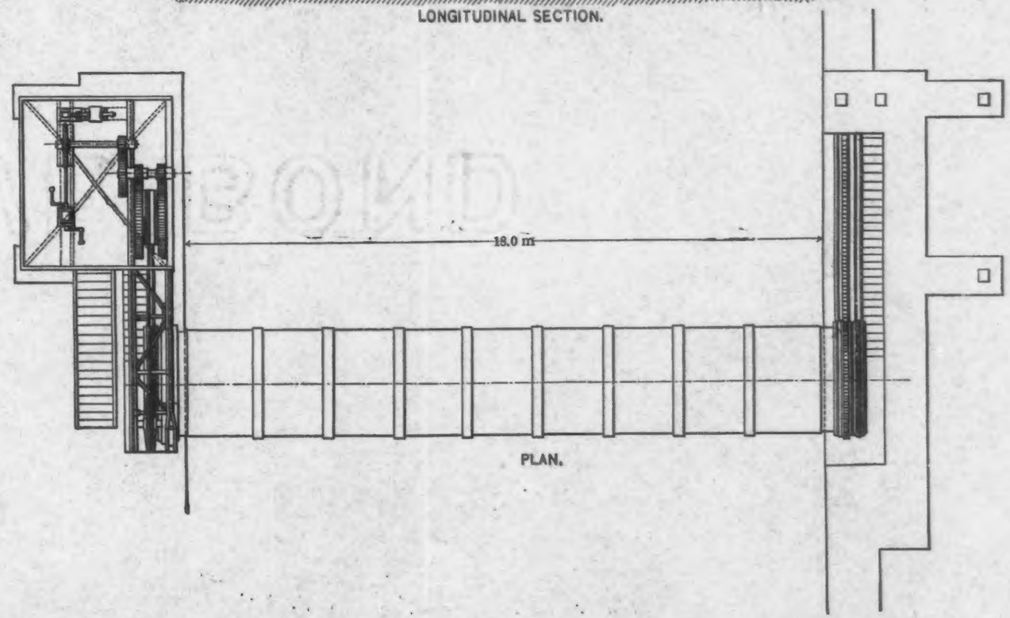
ROLLING DAM AT SCHWEINFURT.



SECTIONAL ELEVATION



LONGITUDINAL SECTION.



PLAN.

rope is acted upon, *viz.*, for rolling up the dam, by action upon the other end, with a reversed motion, it is possible to exert some pressure of the cutting edge upon the sill and secure a tight fit under the dam.

By means of stops engaging at either end of the rolling dam, the cog-wheels can be locked in any position, thereby releasing the tension on the ropes. In general, debris or rubbish is not likely to lodge over the sill, because, by an approaching closure of the aperture, the velocity of the escaping water is increased so much that such bodies are carried through.

The operating machinery consists of an ordinary winch with a self-locking worm gear. The racks, cog-wheels and track are of strong construction and are designed so that any foreign bodies getting into them will drop through or can be removed easily.

The interior of the hollow drum forming the dam contains the ballast tube, of smaller diameter (see Plate XXXI), into which, being open at both ends, the back-water can enter as soon as the dam is immersed to a sufficient depth to require additional weight to overcome the buoyancy. Ordinarily, the water is never flowing over the dam. At the time of the writer's visit it was possible to walk with dry feet through the ballast tube or over the top of the cylinder. On the other hand, the water leaves the ballast tube, without causing inconvenience by its weight as soon as the dam is raised out of the water.

Besides securing a tight fit over the sill, the device for tightening the ends against the masonry is of the utmost importance. This is being done by using annular strips of leather, or can be done by using annular iron rods of circular cross-section lodged between tapering surfaces, such as are generally used with the Stoney gates.

The rolling dams have in their favor simplicity of construction, and great solidity is easily obtained. All parts which are susceptible to injury, such as steel ropes, cog-wheels, racks and stop-locks are placed within the protecting recesses of the masonry abutments; besides they are all on the side of the lower back-water, and can be either wholly protected or are subject to immersion only at rare intervals. In the Schweinfurt dams these parts are placed above the winter water-line, and, therefore, are exempt from injury or obstruction by freezing.

Inspection and maintenance are facilitated by stairways built

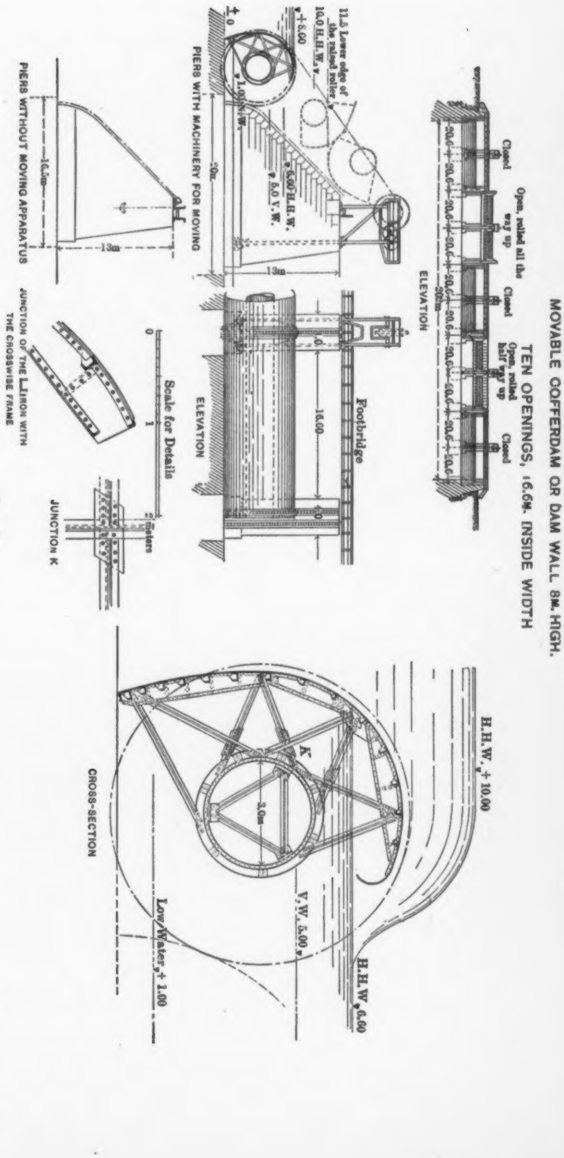

MOVABLE COFFERDAM OR DAM WALL 8m. HIGH.
TEN OPENINGS, 16.6m. INSIDE WIDTH
Closed
Open, rolled all the way up
Closed
Open, rolled half way up
Closed
ELEVATION
11.5 Lower edge of the raised roller
10.0 H.H.W.
+6.00
±0
1.00 L.W.
6.00 H.H.W.
5.0 V.W.
20m
13m
PIERS WITH MACHINERY FOR MOVING
16.5m
13m
PIERS WITHOUT MOVING APPARATUS
Footbridge
16.00
ELEVATION
Scale for Details
0
1
2 meters
JUNCTION OF THE L IRON WITH THE CROSSWISE FRAME
JUNCTION K
H.H.W. + 10.00
H.H.W. 6.00
V.W. 5.00
Low Water + 1.00
3.0m
K
CROSS-SECTION

Fig. 7.

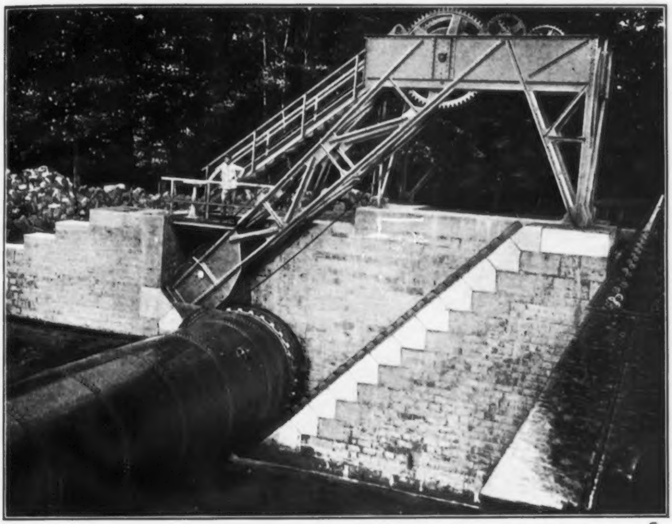


FIG. 1.—ROLLING DAM AT SCHWEINFURT.

FIG. 2.—SECTIONS OF CYLINDER FOR DAM AT SCHWEINFURT.

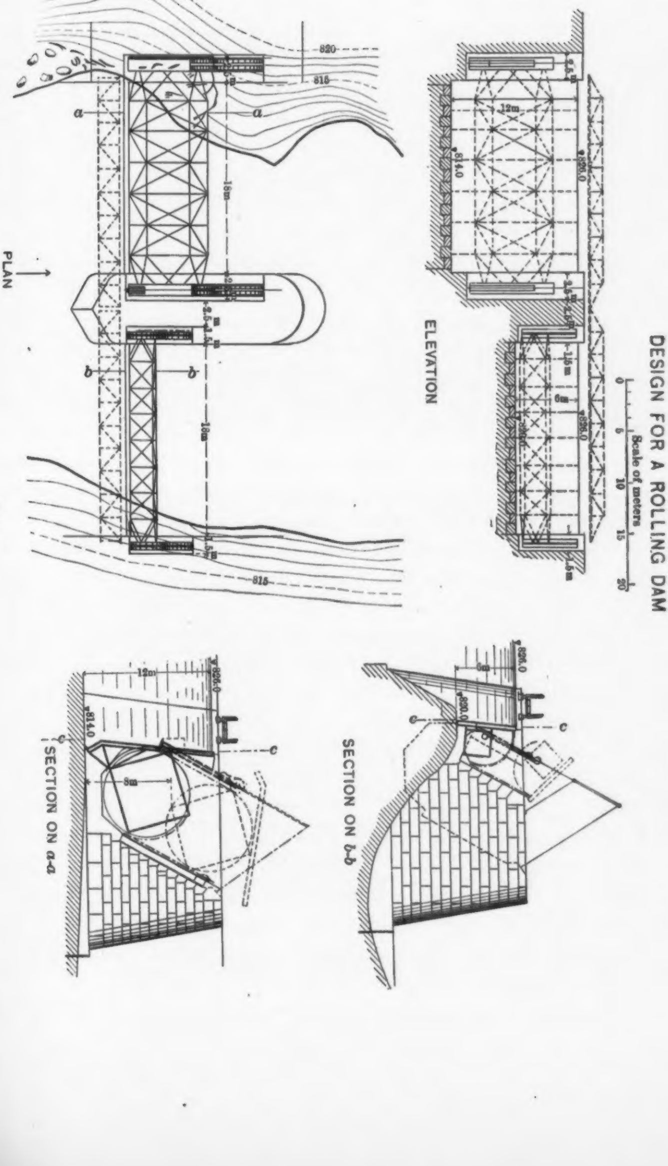

DESIGN FOR A ROLLING DAM
Scale of meters
0
5
10
15
20
PLAN
ELEVATION
SECTION ON a-a
SECTION ON b-b

FIG. 8.

in the recesses of the abutments. Both dams at Schweinfurt have proved a success, but some trouble was experienced with the larger one, closing the gap of 108 ft. Its height being abnormally small in proportion to its length, and the cross-sections being circular, the dam was found to warp under the influence of heat when the sun shone on the top, and the sill had to be cambered. The dam conforms to this camber by deflection at the ends by reason of its weight.

Fig. 2, Plate XXXII, and Fig. 1, Plate XXXIII, illustrate the method of erecting the smaller Schweinfurt dam. The larger dam is illustrated by Plate XXXIV. This dam has a length of 107 ft. 8 in., and a diameter equal to a depth of water of 6 ft. 8 in. It differs from the smaller dam in that it rests on a fixed masonry dam of ogee section, and is operated by machinery on one side only, although a guiding rack is provided in recesses of each abutment. The cross-section of the dam is circular. To prevent the overflow of the water from the upper side of the dam into the recesses of the masonry abutments, triangular fillets are attached to each end of the cylinder. The latter are tightened against the masonry by hemp ropes. The oak timber for the purpose of securing a tight fit over the sill is sunk into the crest of the fixed masonry dam.

On the side from which the operating machinery is omitted, a link chain is provided into which the corresponding teeth at the end of the cylinder engage to prevent any slip. In case both ends of the roller become disengaged, owing to obstructions lodging in the racks, the steel-wire rope will still prevent the dam from descending. The profile of the rack track is a cycloidal curve, compounded of portions of circles.

Fig. 2, Plate XXXIII, and Figs. 1 and 2, Plate XXXV, and also Plate XXXVI, show several views of this dam.

Since these two dams were built, designs differing very materially therefrom have been adopted. Fig. 7 shows a design for a rolling dam to be built in a large river of Europe, carrying large quantities of silt and debris. There are to be ten openings, each of 55 ft., the rolling dam being 27.6 ft. high, for the purpose of backing up water to that depth and still providing an overflow in case of a high stage of water amounting to 33.5 ft. in depth above the dam. The dam proper, in this case, is constructed

FIG. 1.—METHOD OF ERECTING THE SMALLER SCHWEINFURT DAM.

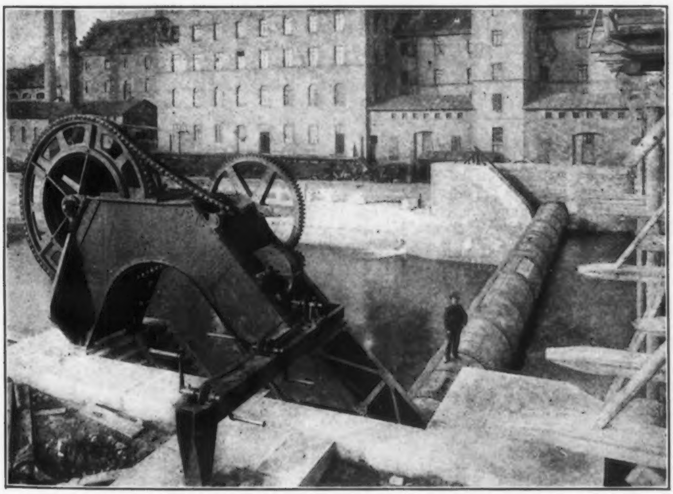


FIG. 2.—THE LARGER SCHWEINFURT DAM.

in the form of an apron attached to the ballast tube, and is circular in cross-section at the ends only.

Fig. 8 is a design for a dam proposed for a turbulent mountain stream which is at times heavily charged with debris. Two openings, each of 60 ft. clear opening, are provided, to back up water to elevations of 40 and 20 ft. over the sill, respectively. The body of the dam is to have a square cross-section, the up-stream face being formed by an angular or plane apron, respectively. Fig. 8 shows an elevation, a plan and cross-sections, the full lines representing the dam when closed, and the dotted lines when open.

At Schweinfurt arrangements are made for operating both dams by hand or by electrical power. Any kind of power available can be utilized. Within a year quite a number of descriptions of this new type of movable dam have appeared in various engineering journals.* It has attracted great interest among hydraulic engineers, and is destined to prove of great usefulness. In many cases it will be found to have superior advantages over other types thus far known.

The plans, photographs and much of the information from which this paper has been prepared were kindly furnished by Chief Engineer, M. Carstanjen, to whom the writer desires to express his gratitude and his hope that the new dam will meet with the success it deserves.

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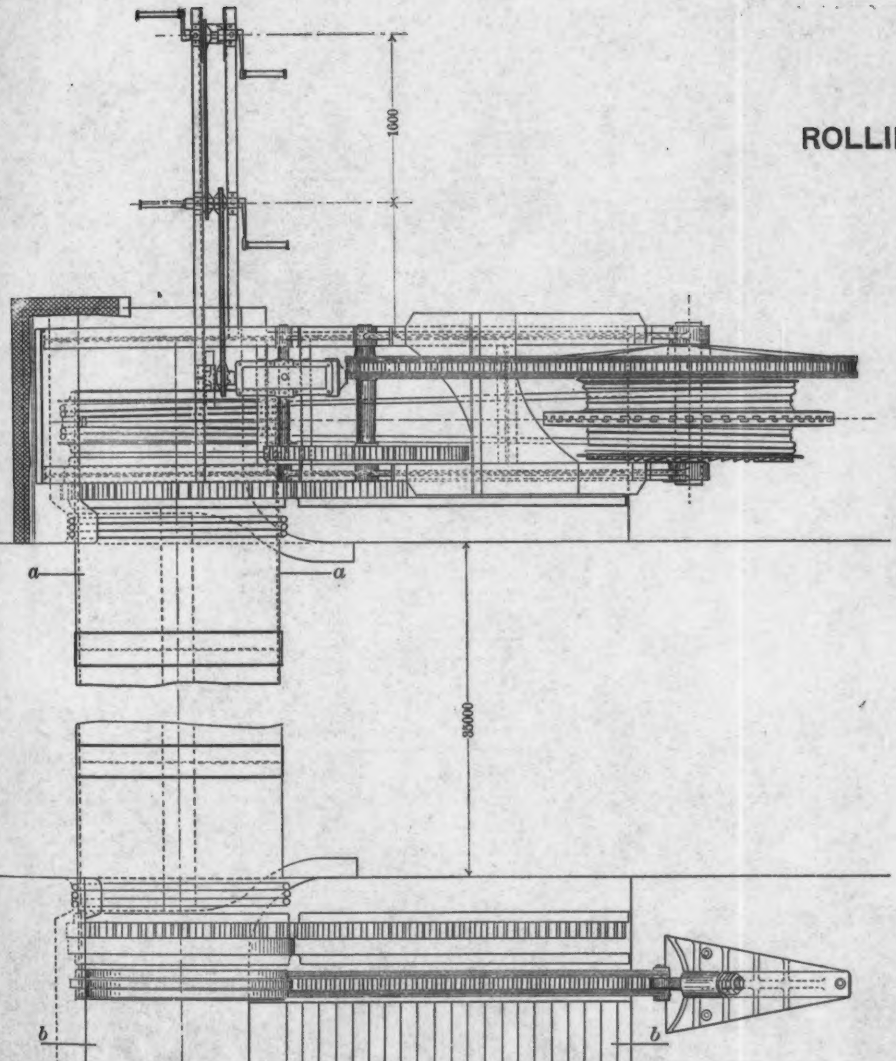
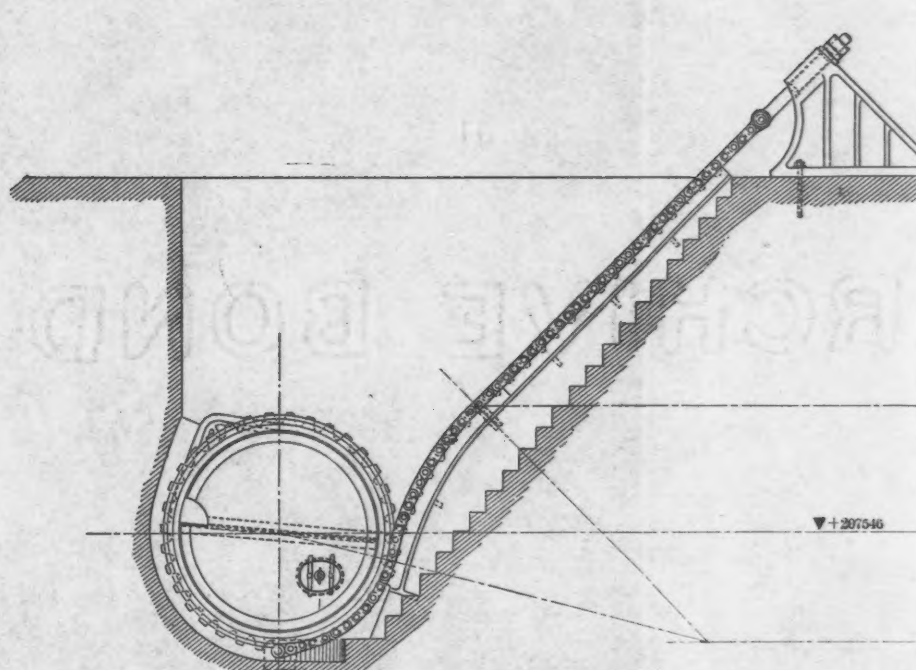
* *Deutsche Bauzeitung; Le Génie Civil; Zeitschrift des Oestr. Ing. und Arch. Vereines; Schweiz. Bauzeitung* (by the writer); *The Engineering Record*, and *The Scientific American*.

ROLLING DAM FOR THE MAIN ARM OF THE MAIN AT SCHWEINFUR

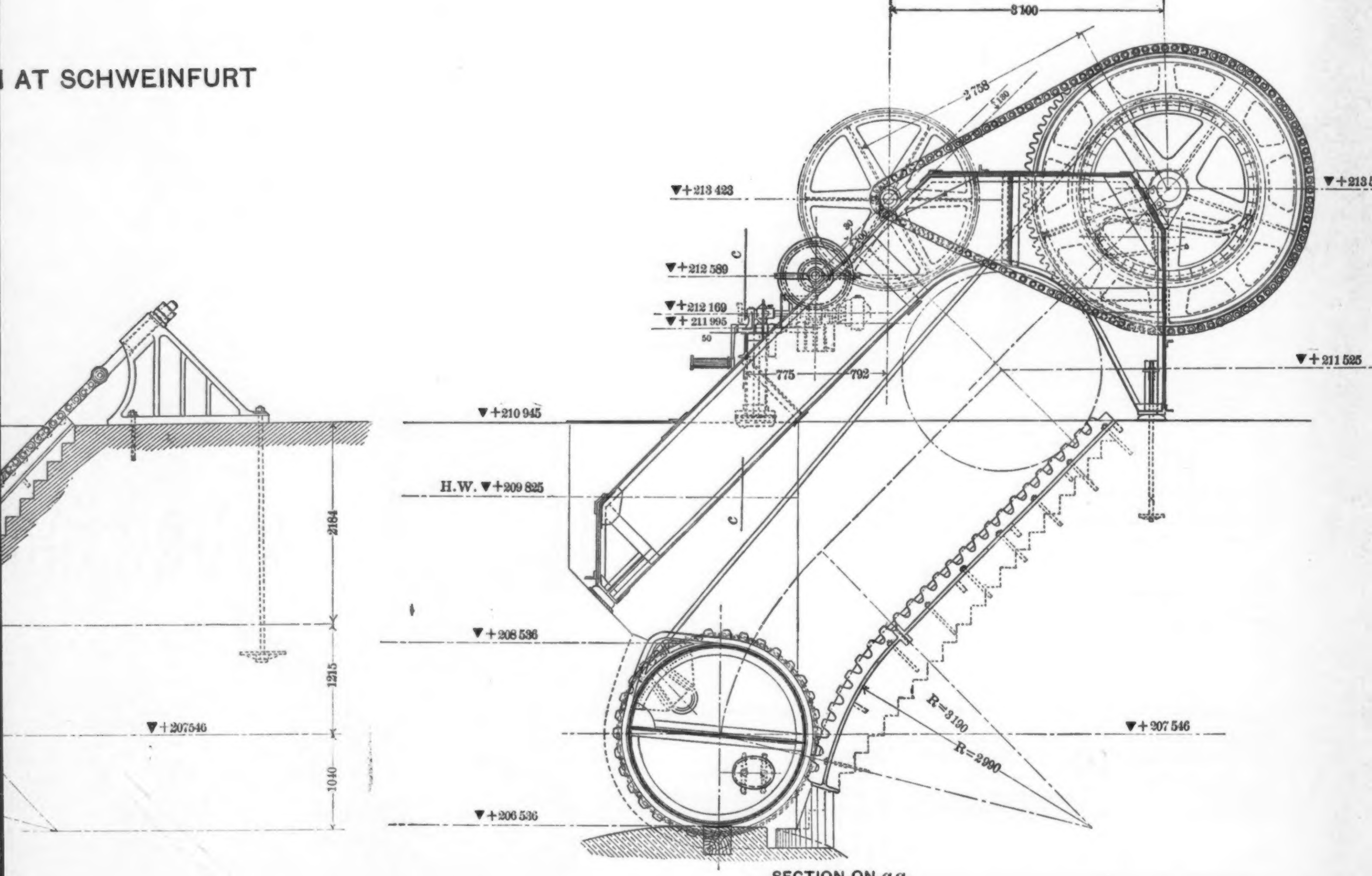


PLAN



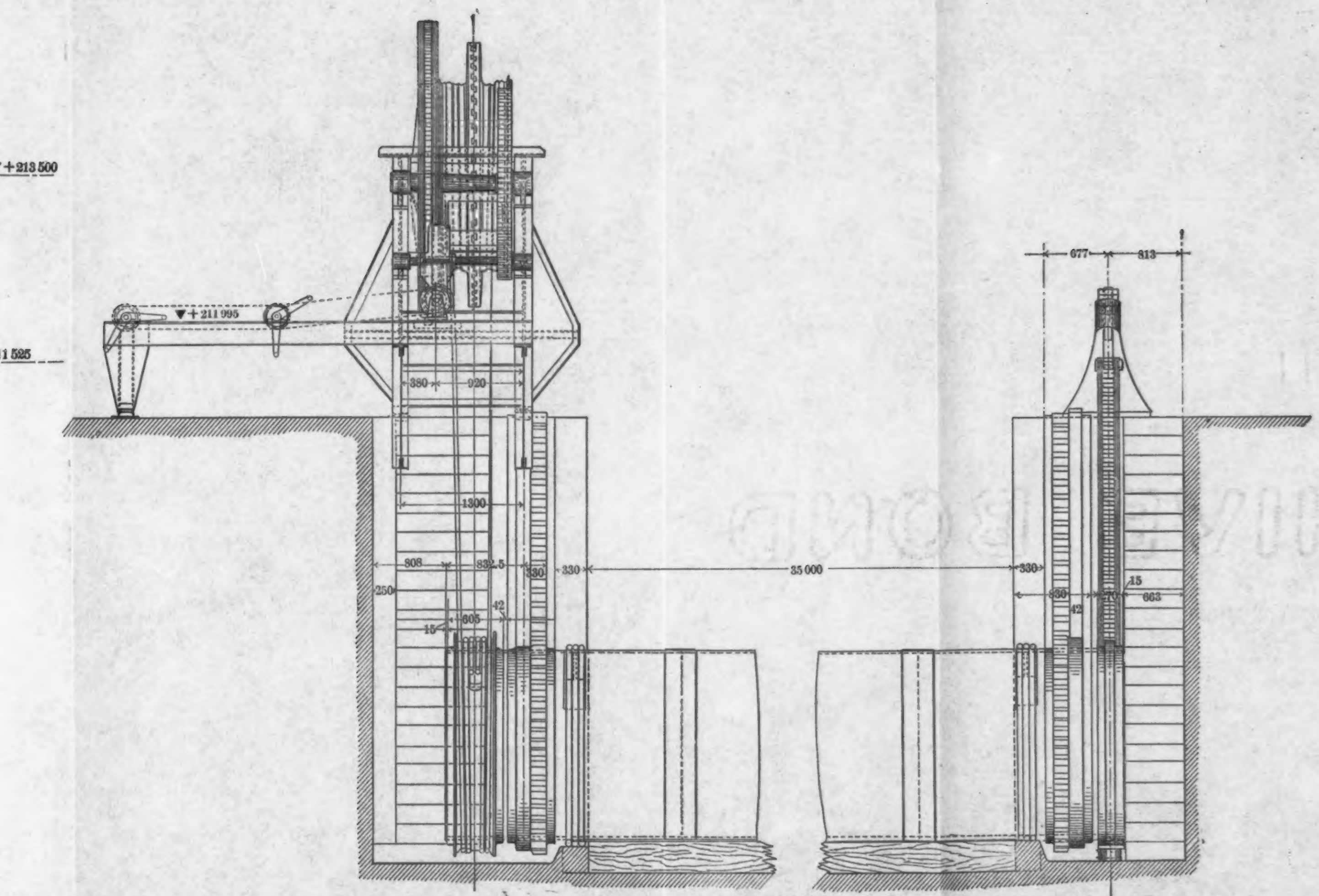
SECTION ON *bb*

AT SCHWEINFURT



SECTION ON aa.

PLATE XXXIV. VOL. LIV. PART D.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
HILGARD ON
ROLLING DAMS.



SECTION ON cc.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS, 1904.

DISCUSSION ON NATURAL WATERWAYS.

By Messrs. William M. Hall, E. L. Corthell, Lewis M. Haupt, A. Miller Todd, C. H. West, Arthur Hider and K. E. Hilgard.

William M. Hall, M. Am. Soc. C. E., Parkersburg, W. Va.— Mr. Hall. Professor Hilgard's paper presents a type of movable dam which the speaker believes is entirely new to American engineers; it is certainly new to our literature on the subject, and it is, consequently, very interesting.

The speaker will not attempt to discuss the paper; but, being employed upon movable-dam design and construction in the Upper Ohio River, his first thought is, can this type of dam be advantageously and economically applied to any part of the Ohio dams, or to the dams to be built in its tributaries?

In this connection, one of the first things which it is desirable to know is the greatest fluctuation of water in the rivers where the rolling dams have been used. On the Ohio, the fluctuation at Pittsburg is about 26 ft.; at Parkersburg, 184 miles further down, it is 53 ft.; below Cincinnati, it is about 70 ft. Where the fluctuation of water is so great, it appears that the rolling dam will be found to be uneconomical, if not impracticable. On our smaller streams, where the fluctuation of water is much less than on the Ohio, the rolling dam may be an advisable type for weirs where headroom has to be provided only for drift and ice.

Professor Hilgard stated, in presenting his paper to the Congress, that the bear-trap dams at St. Paul were considered as failures for carrying drift and ice. The speaker supposes that he refers to the two new bear traps in the Mississippi

Mr. Hall. River dam, a short distance below St. Paul. One of the main objects of those bear traps, as with the bear traps being built on the Upper Ohio, is to pass the ice and drift. Therefore, if, at the present time, they are a failure in that respect, it is a matter of very great interest. Their general design is that known as the reversed Parker type. The speaker would have expected them to fail in passing ice and drift had the direct Parker type been used; but, with the lower leaf folding and not the upper leaf, it will be surprising if they fail in that particular respect.

Mr. Corthell. E. L. CORTHELL, M. AM. SOC. C. E., New York City.—The speaker, on a recent professional visit to Europe, was requested by the Board of Advisory Engineers of the Barge Canals of New York State, of which he is a member, to examine, as far as his limited time permitted, certain features of canals and canalized rivers.

He had with him, on the steamer, the *Scientific American,* which contained a description of the rolling dam described by Professor Hilgard, and he decided to visit it. Before doing so he ascertained from the German engineers, whom he met at the meeting of the International Commission of the Navigation Congress at Brussels, that this kind of a movable dam was coming into considerable use in Germany and was considered there to be a very good dam.

Upon visiting Schweinfurt, the speaker was met by the engineer of the manufacturers and by the German Government engineer-in-charge, who gave him every opportunity to examine the work and the operation of the dam.

He was so favorably impressed with it that he visited the manufacturers at Gustavsburg, near Mayence, and arranged with them to make the general plans and estimate of cost of such a dam as would be required to meet the peculiar conditions in the canalization of the Mohawk River.

These plans have been received and are being examined with a view to their adoption in that river, if found practicable.

The State Engineer's Department is also making plans of its own and is studying all the methods of movable dams used elsewhere and hopes to evolve plans that will meet the differing conditions. It is necessary also to build movable dams on the Oswego and Hudson Rivers, where fluctuations of the water surface from floods and ice conditions in the spring make it necessary to leave the rivers as unobstructed as possible.

The flood and ice conditions on the Upper Main at Schweinfurt are quite similar to those on the above-mentioned rivers in the United States.

Prof. Haupt. LEWIS M. HAUPT, M. AM. SOC. C. E., Philadelphia, Pa.—The subject of the improvement of our natural waterways is one which interests all the members of the profession and all persons interested in

FIG. 1.—THE LARGER SCHWEINFURT DAM, DURING ERECTION.

FIG. 2.—THE LARGER SCHWEINFURT DAM.

Prof. Haupt.

economic transportation; for all realize the immense advantages of water-borne commerce and the reduction of rates incident thereto. Perhaps one of the greatest problems now before this country is the treatment of the Mississippi River, which is the natural drainage outlet of an enormous area covering about 1 200 000 sq. miles. The natural operation of the forces of Nature is that of degradation, erosion taking place in the high lands, the silt being carried by the water is forced through the tributaries and, ultimately, in part to the Gulf. The question of the treatment of this river for navigation is totally distinct from that for the reclamation of land. It is not surprising, however, to find that most residents along this great fertile valley are heartily in favor of the protection of their lives and property. We all feel that this is perfectly natural, proper and legitimate. The levees along the river, extending about 1 000 miles up stream on both banks, have confined the mud to such an extent as to show, from the careful surveys which have been made for the express purpose, that the bed of the stream is rising, and that is the crucial point of the whole discussion. That the bed of the river is rising may, perhaps, be illustrated by the profiles of South Pass, where Captain Eads built the two jetties for the purposes of removing the bar at the mouth. Those plans were successful only after the width between the jetties had been contracted to such an extent that their distance apart was but 650 instead of the original 1 000 ft. In consequence of this over-contraction at the mouth of the river, the discharge has been reduced, and the velocity consequently retarded. So that a partial dam at the mouth of the river, whether it be of water, earth, or wind, or whatever may obstruct the flow of the water, will cause a retardation and sedimentation. These profiles show an average fill of about 4½ in. per annum. Holes of 70 ft. are now up to grade of bottom.

The alignment of the levees also is a point to be considered, because of the great variation in width. In some instances, they are as close together as 1½ miles, and, in others, 22 miles or more apart. Especially is this the case where the large tributaries enter the main stream. These alterations, therefore, are serious obstacles also to the continuity of the current, and create, in part, the great irregularities of slope. In consequence of that condition, there are serious gorges in the stream, as well as very large pools.

These gorges operate as dams, and cause the sediment which the river carries to be deposited in the pools, where the shoals are, therefore, increased in magnitude and are not reduced in depth, save by dredging during low water. So that the present policy of the Mississippi River Commission is reduced mainly to the use of large hydraulic dredges for the purpose of trying to maintain a navigable channel from St. Louis to the Gulf.

Prof. Haupt.

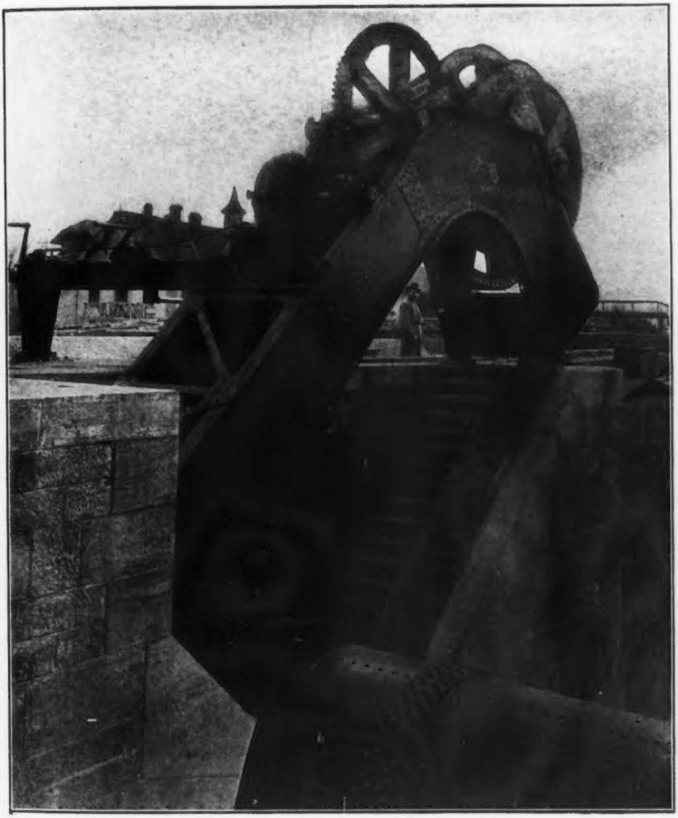
The matter of the revetment of the banks was found to be so expensive that it is only resorted to in extreme cases, where it is necessary to hold them. The comparative cross-sections of the stream, covering a reach of 250 miles, made very carefully by the Commission, show clearly that the bed of the stream has risen about 4 ft., as an average amount, throughout that length, while its banks, especially on the concave sides, have caved in to the extent of about 17 000 cu. ft. for each linear foot of river. This represents an erosion between Cairo and the Red River of some 200 000 000 yd. of materials cut from the sides of the banks and levees in the effort of the river to compensate itself for the reduction due to the congestion by the levees. The river, in other words, is expanding laterally more rapidly than it did before, and is endangering the safety of the levees, so that secondary levees are being constructed back of the first line, with large banks to make them more stable.

In a general view of the treatment of a river of this kind, the speaker's judgment would seem to indicate that so far as possible the floods in the tributaries should be restricted by irrigation works, and by reforestration, and the excessive flood waters should be taken off *en route* and confined in reservoirs of large capacities in the swamps until the crest of a flood has fallen, and then these waters should be returned to the river clarified, thus tending to maintain a more constant depth and a better navigation; and, particularly, the mouth of the river should be opened so as to increase the discharge and let the water out freely to the Gulf.

To explain more fully: In the crevasses which have occurred in the lower reaches of the river, below the mouth of the Red River, it has been found that in about thirty years, in the crevasse known as "The Jump," the river has distributed about 113 sq. miles of mud, which has become a valuable contribution to the wealth of the State and Nation. That land has become available for rice and other cultures, and will soon be high enough for sugar, cotton, and other products of the soil. This and Cubitts Gap have abstracted 18% of sediment from the bars which would have formed at the mouths of these rivers, in case the sediment could not have been deposited in this way, and have retarded the advance of the delta and the raising of the flood-plane.*

There is another element, in the energy of the stream itself, to which sufficient stress has not been given, for the creation of deep, navigable channels. In other words, it is not only the velocity and the volume which produce the depths, but it is the reaction of the concave bank, due to the centrifugal force of the current being operated upon by a resisting medium, which constantly changes its direction. Engineers will probably see how that may be applied for

* For a full consideration of outlets at the mouth, see *Proceedings*, Am. Phil. Soc., Vol. XLIII, No. 175, p. 89.



OPERATING MACHINERY OF SCHWEINFURT DAM.

the removal of bars at the mouths of rivers, by putting in concave resisting works, which will transpose that material to the convex bank on the opposite side of the channel; in other words, producing a lateral instead of a longitudinal distribution. Prof. Haupt.

After the discussion which followed what the speaker said as given above, it seems necessary to add a few words. First, to disabuse our friends' minds of the idea that the speaker is opposing any theory or policy which may exist on their part in the actual conduct of these important public works; and, secondly, with respect to the weight of theory as an element to success. A great deal has been said in regard to theoretical engineers who have had no practical experience, etc. Now, if a theory is based upon natural and physical laws, and is in accordance with the operation of those laws, it must certainly work out as being practically correct.

It is only necessary to add that the statement which has been made in regard to the sedimentation of the river not being correctly stated is merely a question of interpretation of well-ascertained data. The previous deductions are from those which were used and published by the Commission and its engineers. An impartial interpretation of the reports made by Major Harrod himself, in which he published profiles showing the comparative results of these two distinct surveys, twelve years apart, will confirm the shoaling and caving of the bed. If these gentlemen will look in the *Transactions* of the American Society of Civil Engineers,* recently published, they will find a section of the stream for 1894 with its line 4 ft., at least, above the line represented by the average cross-sections of the surveys, 1881-82, and the large area of erosion between low and flood stage also plainly visible.

With reference to the ultimate deposition of the sediment carried by the stream, it may be added that the forces of Nature are still probably as active as they have ever been during the past ages. The same amount of sediment or even more, due to settlement and denudation, is practically carried into the stream. Its slope is undoubtedly less than it was many centuries ago, when the mouth was at Cairo. It is admitted that the alluvium is carried down, as it was originally, by gravity. If a portion is not dropped in the bed in transit then there is only one logical conclusion, and that is, that it must all be carried forward and deposited at the mouth of the stream, which has never been conceded by the most ardent levee advocates.

But the speaker does not wish to be misunderstood as opposing the levee system. On the contrary, he heartily endorses it under certain conditions and for an entirely different reason. He believes that it is a duty to protect our citizens from the encroachment

* Vol. LI, p. 333.

Prof. Haupt. of the floods and thinks the best and cheapest method of doing that is to build earthen dams around the plantations, so that they may be made habitable, and that the country may have the benefit of their products. At the same time, he does not agree with the broad general statement that if there were no levees there would be no commerce, because, prior to the existence of levees, the Mississippi River was carrying a larger commerce in its upper reaches than it is to-day, and the mining interests alone of the Upper Mississippi and Ohio Rivers will continue to provide a large amount of water-borne commerce. The diminution in the commerce is not due to the lack of a navigable river so much as it is to the facilities which are now provided by the railroads in their improvements in rolling-stock and the ratio of dead to live loads, etc.

That will cover most of the points. One other, however, remains, which is important. From personal observations on the actual physical results of crevasses, and from the examinations which were made by Abbot, Forshey, Ellet, Pattison and others, it is concluded that crevasses do not shoal the river below. In every opening on the banks of the river, a reaction is set up, as at the heads of the three Passes, and it is found that, as a consequence, the water is deeper than above, notwithstanding the reduction in volume. So that as a physical fact it is found to be true that the crevasse does not shoal the bed of the stream below, due to the loss of a portion of its discharge. This lateral diversion of sediment by crevasses and reaction, due to a change of direction, may be utilized to great advantage in removing deposits on the bars at the mouths and creating ample navigable channels by a well-designed training wall placed across the bar.

Mr. Todd. A. Miller Todd, Assoc. M. Am. Soc. C. E., Vicksburg, Miss.—Professor Haupt's description of the physical characteristics of the Mississippi Valley and the river itself is all right as far as it goes, but he fails to describe the most important facts, which more than anything else influence the methods and means to be employed in the regulation and improvement of this great stream.

Between the mouth of the Missouri River and the head of the Passes below New Orleans, there are three distinct physical subdivisions of the main stream:

First.—From the mouth of the Missouri to the mouth of the Ohio, 191 miles. In this reach, the river passes through an older geological formation, and, except for very narrow shelves of deposit, the river is confined within its banks throughout its length. The mean slope is about 0.52 ft. to the mile, and the range from low to high water is about 35 ft. There is very little caving.

Second.—From the mouth of the Ohio to Baton Rouge, La., 833 miles. In this reach, the alluvial valley is from 20 to 60 miles wide.

The river follows first the bluffs on the east side of the valley down to 12 miles below Memphis, thence to Helena, it crosses the alluvial plain diagonally; it only touches the bluffs on the west side, however, at Helena, following along within from 12 to 25 miles of the high land to Grand Lake, Ark., thence it crosses again diagonally to the east side touching the hills at Vicksburg, and thence to Baton Rouge, following very closely the hills on the east side of the valley. The entire alluvial valley is subject to an overflow from 5 to 15 ft. deep. The mean slope is about 0.324 ft. to the mile, and the range from low to high water is about 55 ft. The banks are caving almost continuously on either the right or the left shores. This element constitutes the main difficulty surrounding the permanent and systematic improvement of this reach. There are no difficulties attending navigation for vessels drawing as much as 12 ft. except at extreme low water, and then the shoal places constitute probably less than ¼% of the length of the river. Mr. Todd.

Third.—From Baton Rouge to the head of the Passes, 227 miles, the river flows through an almost level alluvial plain. The slope at low water is practically nothing, and at high water is 0.1 ft. to the mile. The range from high to low water at Baton Rouge is 40 ft. and at New Orleans, 20 ft. There is practically no caving in this reach, and very few sand bars and no difficult navigation at the lowest stages. The banks are low and are subject to overflow longer than the upper reaches of the river, and the restraint of the floods constitutes the only general improvement necessary.

Professor Haupt appears to criticise levees, contending mainly that they are not an adjunct to channel improvement, but, on the contrary, that they will cause a filling up of the channel and a consequent raising of the bed of the river. He admits, however, as an economic measure, they appear to be temporarily indispensable, but he thinks that they have been badly executed and that waste weirs should be put in at intervals, and storage reservoirs formed at other places, etc.

The engineers engaged on the river have never failed to consider carefully all the criticisms that have been made by Professor Haupt and other engineers of note, and have carefully weighed every general plan proposed as a substitute, or as an auxiliary, to the present adopted plans. It is a noteworthy fact that in all the schemes proposed, such as reservoirs, waste weirs and outlet systems, the persons proposing them absolutely disregard the great questions of expediency, and whether the necessary engineering details, as to foundations, materials and execution, can be worked out satisfactorily. The engineers connected with the improvement of the river, some of them for nearly a quarter of a century, all

Mr. Todd. agree that, for the proper and systematic improvement of the stream, levees are of primary importance, checking of bank erosion next, and channel regulation the last step. If, instead of about $2 000 000 per annum, five times that amount could be available each year for the next ten years, the above three steps would be the logical sequence of operations.

If it were not for the levees there would be no necessity for channel improvement. The Mississippi River Commission realized this fact at the very outset of its labors. Is it not an axiom of engineering that reclamation must go before the beginning of any great operations looking to the performance of a given project? Especially when reclamation is essential to the very life of the scheme itself. For example, it is generally understood that there will be no steps taken toward the actual excavation of the Panama Canal until all the sanitary measures calculated to render the adjacent country habitable and healthful have been executed. The speaker has heard of no separate appropriation or project being made covering the execution of these sanitary measures. And it would be just as much out of place to make a separate appropriation and place the construction of the Mississippi levees in other hands than the regularly organized body constituted to effect the ultimate improvement of the river. The development of the Mississippi Valley, since even the partial completion of the levee lines, has been little less than miraculous, and it can be shown by mortality statistics that the Valley is just as healthy as the adjacent high lands, if not more so.

It can be shown that the construction and maintenance of the levees have a direct bearing and influence on channel improvement. At flood stages, the river is not only a great volume of water flowing toward the Gulf, but it is also now known that along the bottom of the river there is a vast amount of mud and silt moving, and the force derived from the momentum of the prism of flowing water is the propelling power which keeps this material moving. Professor Haupt seems to intimate that the velocity of the river when confined by levees is less than when not confined, but, as a matter of fact derived from indisputable records, the river, when not confined by levees, rarely attained a velocity of more than 6 ft. per sec., but, in reaches which have been confined, velocities as high as 8 ft. per sec. are not uncommon. And certainly no intelligent engineer will contend that a volume of water flowing at 6 ft. per sec. would have a transporting power greater than a much larger and deeper volume of water flowing at the rate of 8 ft. per sec.

The result of withdrawing large volumes of water from the channel and the consequent reduction in velocity below the outlet are amply illustrated by the effects of levee crevasses on the channel

cross-section below the crevasse. It is a matter of record derived from careful surveys extending throughout a period of twelve months, that below considerable crevasses in the levee line the channel is greatly contracted in area the following low-water season, and bad navigation is always found at low stages immediately opposite and below great crevasses. Mr. Todd.

Professor Haupt's contention is directly opposed to the above facts. He figures out that immediately below a crevasse there should be and always is a scouring out, or, amounting to the same thing, a somewhat less filling up in the channel of the river than there would have been had the crevasse not been open.

The great argument against levees is the theory that they should and are causing the bed of the river to rise. This is a deduction which in the light of scientific reasoning is about as abundantly proven as that "the winters are growing colder" and the "summers are growing warmer." The evidence advanced in support of this theory is an illustration of the unsoundness of the scientific reasoning brought to bear, that is, "the flood level is rising higher from year to year." This is precisely so, and what is more the floods are going to continue to come higher until all the overflow, heretofore spreading over the entire valley, is contracted between levees. Professor Haupt and his school absolutely fail to give any credit whatever to the admitted rise in flood levels below Cairo, as a result of contraction, which, even the simplest of laymen understand, will obtain. This rise in the flood-plane has always entered into the calculations of the engineers and is no more at any of the gauge stations than was foretold years ago. At Greenville, Miss., for example, situated about the middle of the Lower Yazoo Basin, the flood-plane is at least 8 ft. higher than before the levees were built. The range from low to high water, in 1882, was 42 ft., and already a range of nearly 50 ft. has been reached by the floods. Now, if all or any of this increase is attributable to a raising of the bed of the river, it would certainly follow that at low water the readings on the gauge would show a much higher average than before 1882.

However, in 1895, the Greenville gauge registered 2.6 ft. below zero, the lowest ever reached on that gauge, this, notwithstanding the fact that levees had been constructed on both sides of the river in that locality.

Table 2 is a comparison of the low water of 1886 and the low water of 1903. The difference between the two at Cairo, where no levees have been built to influence one way or the other, was only 0.9 ft.

There is certainly no evidence, from the above comparison, of any very alarming raising of the river-bed in seventeen years.

Mr. Todd.

TABLE 2.

Gauge Station.	Lowest gauge readings, in feet.		Difference, in feet.
	1886.	1903.	
Cairo	3.8	2.9	—0.9
Memphis	2.5	1.0	—1.5
Helena	3.0	2.8	—0.2
Arkansas City	3.0	2.1	- 0.9
Greenville	4.2	2.7	—1.5
Lake Providence	2.6	0.7	—1.9
Vicksburg	0.0	0.3	+0.3
Red River Landing	2.8	2.8	0.0
Baton Rouge	2.4	1.8	—0.6
Carrollton	—0.4	—0.5	—0.1

The question of the effect of the levees on the bed of the river* was fully discussed, both *pro* and *con*, at the Annual Convention of the American Society of Civil Engineers in 1903, at Asheville, N. C. B. M. Harrod, Past-President, Am. Soc. C. E., now a member of the Panama Canal Commission, opened the discussion in favor of the levee theory, and Professor Haupt took the other side. In this discussion, attention was called to the reports of the Mississippi River Commission for 1896 and 1897, where the results and comparative surveys made for the express purpose of determining whether there was any evidence of a progressive raising of the bed of the river, which might be attributed to the levees. J. A. Ockerson, M. Am. Soc. C. E., was in charge of these surveys and the working up and compilation of their results, and took part in the discussion referred to above. He summed up the results of these elaborate investigations as follows:

"The thousands of cross-sections of the two surveys were carefully platted, their respective areas measured, and their mean and maximum depths determined. Then comparisons were made between individual sections and between corresponding groups of sections comprising successive pools and crossings. All this entailed an enormous amount of painstaking work, and the conclusions are as follows:

"The crests of the low-water bars, as well as the high-water bars, were found to be lower. About half of the total length resurveyed showed a depression of the thalweg, and about an equal amount showed a slight elevation confined chiefly to the pools."†

The period since 1882 is an infinitely small part of a geological age. It cannot be disputed that a great mass of material is being washed down from the high lands, principally from the west side of the

* *Transactions*, Am. Soc. C. E., Vol. LI, p. 331.
† *Transactions*, Am. Soc. C. E., Vol. LI, p. 357.

Valley, and that, in the past, much of this material was deposited on the adjacent country, but any change, on account of the shortness of the period which has elapsed since observations began to be taken, would barely be perceptible. It is also true that if the levees are completed as contemplated, the river itself will have to be relied upon to transport all the entering material to the Gulf. Mr. Todd.

Professor Haupt contends that the river will be unable to do this. A very simple calculation demonstrates that the river will be able to take care of all the material entering it from any source. E. H. Hooker, in his paper on "The Suspension of Solids in Flowing Water,"* estimates, from the best sediment observations available, that the proportion of sediment to water by weight is:

At Columbus, just below mouth of Ohio......0.000749
At Carrollton, near the mouth of Mississippi..0.000601

These are mean results, covering the period of one year.

In Bulletin *E*, U. S. Department of Agriculture, page 27, it is estimated that the mean annual discharge at

Columbus equals 487 350 000 000 cu. yd.
Carrollton equals 724 360 000 000 " "

By combining the above data, it is estimated that 212 000 000 cu. yd. of silt are discharged in suspension at Columbus. Only two silt-bearing streams, the Arkansas and the Red Rivers, enter below Cairo. The Arkansas adds about 26 000 000 cu. yd, of silt annually. The amount added by the Red River is neglected because the discharge, not passing Carrollton, through the Atchafalaya and Bayou La Farche, is about equivalent to the discharge of the Red. The silt passing Carrollton amounts to 260 000 000 cu. yd., 22 000 000 yd. more than can be accounted for, as entering from all the tributaries. The carrying capacity should certainly be as much with a river when contracted by levees as before, hence there appears to be plenty of capacity to retain material in suspension and to transport all the entering material throughout its length.

Professor Haupt, not satisfied with attacking the levee principle, also thinks that they have been located badly. This is admitted also, but they have been located as they are from a financial necessity. His ideas as to correct location, however, would, if applied, have worked untold harm to the river problem as a whole. He contends that where the levees approach within 1½ miles of each other on the opposite banks of the river, such places constitute "gorges," hampering the free flow of the water to the Gulf, and he suggests that they should have been located a fixed distance apart so as to clear all the long bends, where they exist, and thus do away with the so-called gorges. The speaker has, during the past few months, been making a study of this very matter, and the conclusions ar-

* *Transactions*, Am. Soc. C. E., Vol. XXXVI, p. 281.

Mr. Todd. rived at seem to demonstrate that the setting back of the levees, so as to clear the series of bends in the reach between Arkansas City and Greenville, has lowered the flood-plane at Arkansas City only about 0.6 ft., while at Greenville, 45 miles below, and thence nearly to Vicksburg, 135 miles, the flood level has been raised over 2 ft., due to the cut-off conditions existing at extreme high stages between the two points mentioned. Levees 10 miles apart cause very nearly the same raising effect as when they are close together, because the batture between the levees and the river, in nearly all cases, would be grown up with thick underbrush and timber, and the discharge over the bank would be practically negligible, except along the open right-of-way of the levee and across the short cuts, where narrow necks intervene; and, when extreme heights over the natural banks are reached, the rush of water across these narrow necks upsets all normal conditions of flow, and causes an unstable condition of affairs generally. Already cut-offs have been narrowly averted, which, if they had occurred, would have worked untold damage to the river improvements and the adjacent riparian interests. Professor Haupt's plan might be all right, if the batture between the levees were cleared of all obstructing timber, underbrush, etc., and the water might be lowered in the upper reaches of the river, in the lower reaches, however, the effect would be the reverse. From Cairo to Baton Rouge, the main channel would be subject to cut-offs and very violent changes during floods.

The fault with levee location to date is that they have been located too far apart, because of lack of funds. It is now realized that the ideal location would be to follow the trend of the main trunk as closely as possible, building the levees as nearly a uniform distance apart as is consistent with the constantly caving banks.

Waste weirs are suggested to draw off the water and thus to reduce the water level, and it is claimed that the water drawn off will fill up the low places, sloughs, etc., and these will eventually be reclaimed by sedimentation.

The speaker had a visible demonstration of the effect of a waste weir, by noting the effects of a large crevasse which occurred about three miles below Greenville at about the top of the flood in 1903. Greenville is about the middle of the Lower Yazoo Valley, there being about 100 miles of levee below this point to the end of the levee system, below which the back-water has access up the Yazoo River. The estimated discharge of this crevasse was 170 000 cu. ft. per sec. for several weeks. The gauge was lowered 2 ft. at Greenville almost immediately; at Arkansas City, 45 miles above, the effect was not felt, and, at Vicksburg, 135 miles below, the river just became stationary. Here is an average lowering of only about 1 ft. from Arkansas City to Vicksburg, as a result of the 170 000 cu. ft.

per sec. less discharge in the channel. But every foot of the country between Greenville and Vicksburg was overflowed. There were estimated to have been 860 sq. miles overflowed solely from the crevasse, the overflow water being from 1 to 15 ft. deep. Mr. Todd.

Moderate quantities of river water may be drawn off through or over the levees at some future time, for fertilizing purposes, but there will never be enough drawn out to lower perceptibly the high-water level, or to reclaim very appreciably any of the swamp areas by deposit. Hence, it is the levee engineer's first consideration to raise the embankments high enough to restrain the maximum floods.

Reservoirs may be all right in principle, but it can be demonstrated that any scheme or project at all likely to work out as efficiently for the purpose of reducing flood levels is many times more costly than the levee system.

As to outlets, practically the same remarks will apply as were set forth in regard to waste weirs. Outlets may possibly be constructed on the west side of the Valley, but it has never been demonstrated satisfactorily that they would serve to reduce the flood levels enough to afford very great relief, and it is absolutely certain that the proposed auxiliary channel for the river would have to be leveed to prevent it from overflowing the low lands through which it would have to pass.

Next to the floods which have been practically controlled where levees have been constructed (except for extreme high floods), comes the problem of the unstable character of the river banks, especially in the second reach of the river, between Cairo and Baton Rouge. It can be shown that in this reach the caving banks are the indirect cause of all the bad navigation at low stages. And it has been found that the only way to stop successfully the caving of the banks is by the standard fascine-mat revetment, which costs between \$30 and \$35 per lin. ft. of bank protected. Sufficient funds have never been available to attempt revetment in any continuous and consecutive project. If all the caving could be stopped, and the high and low-water channels be made practically coincident by properly located levees and spur-dikes, then the river bed would be much more stable than it is now. The low-water channels would be well defined and fixed, and could the first two steps, mentioned at the beginning of these remarks, be brought to a successful completion, the speaker is certain that between Cairo and the Gulf there would never have to be any further measures taken to improve the low-water channel, it would be sufficient for all classes of river navigation.

The conditions, as to caving banks in many reaches of the river, are being steadily improved by the lengthening out of the river bed, as a result of the caving banks in the bends and the prevention of cut-offs across the necks.

Mr. Todd. As long as the rapid changes in the river bed occur as they do, the shoal being found first at one crossing and then at another miles away, and often between rises the shoals form in entirely different places for the same locality, it is not practicable to undertake any permanent works of channel regulation, such as the single reaction jetties or training dikes proposed by Professor Haupt. This fact has forced the adoption of dredging as a means of maintaining a navigable channel between Cairo and Vicksburg at all seasons of the year, simply because they can be moved up or down the river with facility and can attack the shallow places wherever and whenever they show up, and, for this purpose, they have been entirely successful.*

It is extremely hard for a person not intimately acquainted with the Mississippi River in all its parts and all its enormous forces, which are being ceaselessly applied to tear down its own creation as well as the weak efforts of man, to realize the immensity of the problems involved in the whole scheme of improvement, and much more difficult to dictate innovations involving entire changes of plans and projects and the expenditure of funds amounting to sums far beyond what the most optimistic would like to see made available for the completion of the plans already adopted, which plans, as far as they have been executed, have proven so successful and beneficial to all the interests concerned.

Mr. West. C. H. West, M. Am. Soc. C. E., Greenville, Miss.—It is not the intention of the speaker to discuss this subject in either a technical or speculative manner, but simply to call attention to the fact that the theory advanced by Mr. Haupt regarding the levee system of the Mississippi River is not supported by the data obtained, or the conclusions reached, by those engineers who have made careful surveys for a study of the subject.

A. M. Todd, Assoc. M. Am. Soc. C. E., has already referred to the very able and exhaustive discussions on this subject which were published in full in Vol. LI, of the *Transactions* of the Society.

The improvement and control of the Lower Mississippi River is an engineering problem of national importance, and, during the past twenty-five years, much time and study have been devoted to it by eminent engineers, all of whom have arrived at the conclusion that the building of the levees is both an important and a necessary feature of the improvement of the stream. It, therefore, appears a little strange that some engineers who have not been connected with this work should seem to be imbued with the idea that the levee system is wrong in principle; that its effect is to cause the stream

* For a description of the dredging and the machines used, see the very able paper presented to the International Engineering Congress, 1904, on "Hydraulic Dredging on the Mississippi River," by F. B. Maltby, M. Am. Soc. C. E., U. S. Asst. Engr. in charge of the operations of the dredges on that river.

to silt up, and the bed to rise higher and higher, as the levees are raised in height. On the other hand, let us examine the record of surveys made under the direction of the Mississippi River Commission, the only trustworthy source of information on the subject. Mr. West.

This Commission caused a careful survey of the river to be made in 1881-83, from Cairo south, in which cross-sections of the stream were made at intervals of about ¼ mile, with about seventy-five soundings to each cross-section. In 1894-96 a similar survey was made from the mouth of White River to Donaldsonville, a distance of 472 miles, being on that part of the river on which there had been made the greatest improvement in the levee system in the interval between these surveys. The two surveys were referred to the same bench-marks, with elevations from the same datum plane, in order that the two sets of cross-sections might be readily and accurately compared. This comparison indicates that, instead of the bed of the river rising, there is a tendency to scour at the shoal places, thereby creating a more uniform depth and greater channel capacity. Surveys similar to those mentioned are now in progress and, when completed, will furnish additional and more definite information on this subject. The interval between the survey of 1881 and that of 1894 was too short, and the condition of the levees too incomplete to have expected any very decided results, but such changes as had taken place were in the direction of an improvement of the channel.

The Mississippi River is not as shallow a stream as many persons seem to think. At extreme low water, the depth along most of the distance below Cairo is 40 ft. or more, and it is only over the bar crossings that the water is ever shoal enough to interfere with navigation. The bars that extend across the stream are usually comparatively narrow ridges, and occur where the channel crosses from the end of the concave bank on the one side to the beginning of the concave bank on the other side of the river. If all the material in these cross-shoals were cut away, and deposited in the long deep pools above and below, there would be a depth, all the way south of Cairo, of 35 ft.—probably more—at extreme low water. The high-water plane, being about 50 ft. above that of low water, would, consequently, make a depth of 85 ft. or more at extreme high water. Of course, we cannot expect that this ideal condition will ever be realized, but the tendency is in that direction.

For many years reliable gauges have been established at intervals along the river, and daily records kept of their readings, and it is only necessary to refer to these records to be convinced that the low waters of recent years are several feet below those of earlier years, with equal depths of channel and discharge. From this it is evident that there has been a depression in the bed of the river.

In the improvement of the Mississippi River, the work is divided

Mr. West. into three distinct classes. The first—the most important, and without which there would be little necessity for the others—is the levee system, or the building of earth embankments to confine the floods of the river to narrow limits. The second is the revetting of the banks to prevent caving at points where it would be very disastrous, as along city fronts; at points where important portions of the levee are menaced; or where cut-offs in the stream are threatened. The third is dredging, the principal object of which is for the purpose of cutting through the cross-shoals where they interfere with low-water navigation. All these works—levees, revetment, and dredging—are in their infancy, so far as their ultimate extension and application are concerned, but enough has already been accomplished to demonstrate that each is correct in principle.

The levees are incomplete in height and section, and many extensions remain to be constructed in the lower ends of the basins. The total volume of the existing levees is only about two-thirds the amount that, it is estimated, will be required to build them to the height and section necessary to confine the maximum floods. Crevasses that have occurred in the past, therefore, must not be attributed to the system being wrong in principle, but solely to the incomplete condition of the works. That the immediate effect of confining the floods between levees will be to raise the flood-plane is, of course, to be expected, simply because of the greater volume of water that must pass between them.

A close observation and study of the partial effect of the incomplete levee system leads to the conclusion that when the floods have been completely confined to the channel, the effect will be to scour away the crests of the cross-shoals, and deposit the material so removed into the long deep pools that intervene, thereby tending to create a more uniform depth, greater discharging capacity of the channel and a consequent lowering of the flood-plane.

In the treatment of the Mississippi River problem, the levee system is justified by experience, not only because it tends to the improvement of the stream for navigation, but because, by preventing the annual overflow of the valley, it has already made it possible to bring to a high state of development the greater part of the 30 000 sq. miles of fertile alluvial lands bordering the river (that would otherwise have remained a wilderness), thereby adding materially to the wealth and commerce of the country.

The levee system, as mapped out, is far from completion, but the work thereon is steadily progressing and will continue until it has been brought to such a state of efficiency as will guarantee to the dwellers in the valley full protection from overflows, and which, in conjunction with bank revetment and low-water dredging, will give to the country a navigable stream without obstructions at any stage of water, and stable ports at all the cities and towns along its course.

With all due deference to Mr. Haupt, his theory, though very interesting, does not harmonize with the facts in the case, as gathered from careful observations and surveys. Mr. West.

Those engineers who are charged with working out this problem have not been wedded to any theory, but seek only to discover the principles involved, and be guided by them.

ARTHUR HIDER, M. AM. SOC. C. E., Greenville, Miss.—As the general plans and methods now being employed in the improvement of the Lower Mississippi were brought into the discussion, and having personally been engaged on that work from its beginning, the writer thinks it might be of interest to add to the able paper of Mr. Marinkelle on the development of natural waterways in The Netherlands a short description of the general plan and methods employed, with the results obtained during the past decade, both in the improvement of the river itself between Cairo and its mouth and the reclamation of the valley from disastrous overflows. This part of the river covers a distance of upwards of 1 000 miles, flowing through alluvium of its own formation. Mr. Hider.

The problem of regulating the channel of the Mississippi River with a view to the establishment of a more stable regimen and the protection of the contiguous basins from overflow during seasons of extreme high water, which occurs at irregular intervals, every few years, is one of great magnitude and demands the highest degree of engineering skill which can be applied only after long and careful study, aided by the experience gained from the application and trial of different methods.

When the immensity of the problem is considered: that of securing from disastrous floods the land on both sides of the river subject to overflow by the construction and maintenance of a double line of levees upwards of 1 000 miles in length; the protection of caving banks to render permanent the very foundations on which these levees stand; and the prevention of the deterioration of the channel caused by the immense quantity of material, transported from above and eroded from the banks, that is carried forward and deposited as shoals and sand bars, added to the problem of the regulation of the navigable channel at low water, it need not be wondered—since the results, which, in many instances, have been accomplished by tentative methods, afterwards abandoned, or modified from experience gained from the results of earlier work—that comparatively little seems to have been accomplished when the ultimate improvement of the entire river is considered.

The difficulty of making complete and permanent the improvement of a river flowing in an alluvial bed with a width at bank-full stage of from 2 500 to 5 000 ft. or more, and a maximum depth of from 60 to 100 ft. at flood stages, with an oscillation in stage of upwards

Mr. Hider. of 50 ft. between extreme high and low water, and a discharge varying from 150 000 cu. ft. per sec. at extreme low water to 2 000 000 cu. ft. per sec. at flood stage, can hardly be realized by any one who has not been called upon to battle with all the elements which must be either guided or controlled in order to arrive at a successful solution of the problem.

That great progress toward its final solution has been made cannot be doubted, although what has already been accomplished may appear to be insignificant when compared with the ultimate complete improvement of the river, which will require many years before final accomplishment.

As the work of river improvement progressed the problem naturally divided itself into three distinct heads, *viz.*, (1) restraining the floods, (2) protection of banks from caving, (3) improvement of the channel by revetment, dikes and dredging.

Levees were first constructed as a means of restraining floods and to prevent overflow without regard to any influence they might have on channel regulation. As the system was extended upstream from the lower portion of the river, and both banks of the river were leveed, it became clear that their effect in restricting the high-water width to a more regular distance between banks at high water had a good effect on the channel at medium and low stages, and that levees were an important adjunct to channel improvement.

During the last ten years very much has been accomplished by levees in restraining the devastation of floods. They have also undoubtedly been of great benefit to navigation where built at approximately uniform distances apart on both sides of the river, in tending to maintain the high-water channel and that at bank-full and lower stages more nearly in the same position, as well as in affording landing-places in the interest of commerce.

It has been proposed, where the sinuosities of the river are very great, or where the bends are extremely long and the reversal sudden, leaving a long, narrow point or peninsula between the river above and below, and where the building of levees around the points would entail a very large expense, to build out dikes or spurs from the controlling levee line so as to regulate the excessive width of the river at these places at high water, and thus make the width of river at extreme high-water stages conform more closely to that at bank-full and lower stages. This would have the effect of equalizing the slope at high stages, prevent abnormal velocities at high water, and thus reduce erosion of the banks, render the high and low-water slopes more nearly parallel and prevent, to a great extent, the filling up and obliteration of the previous low-water channel by deposit at high stages, due to divergence of the high-water from the low-water channel. In order to derive the greatest benefits

from levees as aids to the improvement of the river channel, it is essential that they should confine the flood waters to approximately a uniform width, and their location be such as to follow as nearly as practical the sinuosities of the river. Mr. Hider.

As the levee system was extended farther upstream, it was found necessary to increase the dimensions of the levees both in height and section. During the last ten years, the section of these levees has been more than doubled. The average height has increased from, say, 10 to 16 ft. The standard section now has a top width of from 8 to 10 ft. and side slopes of one on three, reinforced with a banquette on the land side from 20 to 40 ft. wide, extending to within 8 ft. of the top of the levee.

The result of the extension of the levee system has necessarily been an increase in the flood height, due to confinement of the flood waters between the levees, but there seems to be no evidence from any authentic or extensive surveys that there has been any perceptible raising of the bed of the river due to the construction of levees.

To substantiate the above statement, reference is made to the papers* by B. M. Harrod, Past-President, Am. Soc. C. E., and J. A. Ockerson, M. Am. Soc. C. E., in which this phase of the subject is thoroughly discussed.

The complete protection of the valley from overflow will not be attained until the levee system is finally finished. It is estimated that the system is now about two-thirds complete.

The amount that has been expended for levee protection for this rich alluvial valley has been returned manifold in protection to life and property; enhanced land values; increased productiveness and the opening up of thousands of acres of land which otherwise would practically remain a swamp, incapable of cultivation, giving employment to thousands and adding to the wealth, prosperity and health of the community. These results are undoubtedly due to the construction of levees, and the expenditures have been justified and fully endorsed not only by able engineers familiar with the conditions, but by the inhabitants of the valley; in fact, it is the only practical method of affording relief from floods to this section.

The primary object expected to be attained in protecting caving banks was the regulation of the river channel. In the earlier improvements, experiments were made by constructing dikes of piles and brush, both lateral, parallel with the channel and at right angles.

While these were measurably successful in accomplishing the object for which they were constructed, namely, channel rectification at low water, it was found that at higher stages the pile dikes presented obstructions to the free discharge of the river, and after

* *Transactions*, Am. Soc. C. E., Vol. LI, pp. 331, 356.

Mr. Hider. a few years their further construction was abandoned; submerged groins or abatis dikes have since been constructed to divert the current and deepen the channel at low water at certain localities; these have proved more successful.

At present, the main and practically the only reliance for channel rectification is bank revetment and dredging. Two distinct types of subaqueous revetment are now in use:

a.—The continuous fascine mattress made in widths varying from 200 to 350 ft. and in lengths of from 600 to 1 500 ft., constructed *in situ* and sunk in one piece. This form is used on the upper two-thirds of the part of the Mississippi River above referred to. In this part of the river, the bank caving is the most active.

b.—The sectional mattress made on a wooden frame with three courses of willow brush laid at right angles to each other; these sections are about 112 ft. long and from 100 to 350 ft. wide. The sections are constructed where material is convenient and towed to the point where they are to be used and sunk, one section lapping the other. Mats of this construction, with crib dikes superimposed, have been used with success in New Orleans Harbor. The sectional mats without the cribs have also been used in revetting caving banks above New Orleans.

The method of subaqueous bank revetment used in the earlier work, which consisted of narrow light woven willow mattresses, has been greatly improved and perfected within the last ten years. The best form is now considered to be the fascine mattresses. These are constructed from 200 to 350 ft. wide, and in continuous lengths from 600 to 1 500 ft. These mattresses are sunk along the concave caving bends in depths of water from 40 to 80 ft. to prevent scour along the toe of the slope. The fascines are made from 12 to 15 in. in diameter of willows fastened by wire strand to wire cables running lengthwise of the mattress; each fascine is made so as to be continuous the entire width of the mattress, which, as stated above, is from 200 to 350 ft.

The mattress when finished is sunk in place where constructed by loading it with stone. The upper bank above the water-line is brought to a slope of between 1 on 3 to 1 on 4 by hydraulic grading; the slope is then covered with stone rip-rap from 8 to 12 in. thick, to withstand the eroding action of the current.

The work of bank revetment has of recent years been confined principally to the prevention of further caving of banks in front of towns and villages, and also to the protection of important levee lines, where it would be extremely expensive to find a suitable location for a new levee within a reasonable distance of the river bank, due to the topographical features of the ground behind, which is frequently so interspersed with old sloughs and lakes that a suit-

able foundation for a new levee could not be secured unless by abandoning a large amount of valuable land. Mr. Hider.

The revetment work built during the past ten years has been, on the whole, quite successful and has been instrumental in saving several towns built on the bank of the river from partial if not entire destruction, among which may be enumerated Columbus, Hickman, New Madrid, Carruthersville, Helena, Greenville and Lake Providence; towns of from 2 000 to 10 000 inhabitants.

Revetment has been equally successful at many other points, among which may be enumerated Memphis and New Orleans, where valuable property was in jeopardy, for the purpose for which it was constructed, *viz.*, the protection of important levee lines and the prevention of cut-offs, the effect of which would be disastrous to the levees below and destructive of the regimen of the river. Extensive revetment work is now in progress. At present there are 40.31 miles of completed bank protection which can be considered as a permanent improvement.

This work is classed under four different heads, *viz.*:

Protection of towns and cities	20.00	miles
Protection of important levees	3.10	"
Prevention of cut-offs	5.00	"
Rectification of channel	12.21	"
Total	40.31	miles.

The later improved revetments cost for original construction from \$30 to \$35 per lin. ft., depending upon location, width of mats, etc. The annual maintenance charge to keep the same in good condition for the past fifteen years has been about 2¼ per cent.

While revetment work, if made continuous along the entire length of the river where the banks are caving, would, by rendering the river banks stable, together with the construction of levees to prevent the valley from overflow, be a final solution of the problem, the great first cost of the revetment work, *viz.*, from \$30 to \$35 per lin. ft., when the length of the river is considered, and the time necessary for its construction is taken into consideration, renders essential some other method, in the meantime, to keep a navigable stage at bars and crossings during low water.

No cheaper or more satisfactory method than dredging has, as yet, been devised for this purpose. This dredging work is needed only during the lowest stages and then at only comparatively few shoal crossings confined to the upper part of the portion of the river under discussion. The greater part of the dredging required is within a distance of 500 miles of Cairo. In a valuable paper on dredging which was read before this Congress, F. B. Maltby, M. Am.

Mr. Hider. Soc. C. E., states that a navigable depth of practically 9 ft. has been maintained during low-water seasons. This is ample water for the boats navigating the river.

The immensity of the problem of improving the Mississippi River can hardly be overestimated, and, although much progress has been made toward its final solution, a great deal remains yet to be accomplished.

Prof. Hilgard. K. E. Hilgard, M. Am. Soc. C. E., Zurich, Switzerland. (By letter.)—Mr. Hall seems to have misunderstood the writer. He referred to the steel-frame bear-trap gate at Minneapolis and not at St. Paul, as not having given satisfaction. It forms a part of the lower dam of the St. Anthony Falls water-power plant of the Minneapolis Mill Company, and according to William de la Barre, M. Am. Soc. C. E., who had it built, gave trouble caused by ice, drift, and especially by saw and flour-mill dust, so that it was replaced by an ordinary sluice gate. The writer was not aware that there are two new bear traps in the Mississippi River dam "a short distance below St. Paul." The new timber bear-trap gate in the Government dam at Meeker Island in the Mississippi above St. Paul has so far not caused any trouble, but is, on the contrary, expected to give entire satisfaction by the engineers in charge.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

PUMPING MACHINERY.

Congress Paper No. 58.

THE PRINCIPLES OF DESIGN OF VELOCITY PUMPS.

By William Mayo Venable, Assoc. M. Am. Soc. C. E.,
New York City, U. S. A.

Congress Paper No. 59.

MUNICIPAL WATER-WORKS PUMPING ENGINES.

By Irving H. Reynolds, M. Am. Soc. M. E.,
New York City, U. S. A.

Discussion on the Subject by

Carl George de Laval, East Cambridge, Mass., U. S. A.
W. F. M. Goss, La Fayette, Ind., U. S. A.
R. C. P. Coggeshall, New Bedford, Mass., U. S. A.
H. F. Dunham, New York City, U. S. A.
Richard J. Flinn, Boston, Mass., U. S. A.
Elmo G. Harris, Rolla, Mo., U. S. A.

W. B. Gregory, New Orleans, La., U. S. A.
George Higgins, Melbourne, Victoria.
James Alex Smith, Melbourne, Victoria.
J. N. Chester, Pittsburg, Pa., U. S. A.
Charles A. Hague, New York City, U. S. A.
J. T. Fanning, Minneapolis, Minn., U. S. A.
M. L. Holman, St. Louis, Mo., U. S. A.
G. O. M. Olsson, Stockholm, Sweden.
Otto H. Mueller, Berlin, Germany.
William Mayo Venable, New York City, U. S. A.
Irving H. Reynolds, New York City, U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 58.

PUMPING MACHINERY.

THE PRINCIPLES OF DESIGN OF VELOCITY PUMPS.

By William Mayo Venable, Assoc. M. Am. Soc. C. E.

Pumps may be grouped in two classes, the first class containing those in which part after part of the liquid is entirely cut off from the source of supply by a movable partition and subjected to pressure, or lifted, in a confined chamber; and the other class containing all those in which at all times there is a continuous open channel from the suction side to the discharge side of the pump.

The first class may be subdivided into types, among which the ordinary piston type with reciprocating motion is the most common. In this type the motion of the liquid within the cylinders is intermittent and alternating in direction, and valves are essential to the operation of the pump. In this class is also the rotary fire-engine pump, in which the partition consists of two or more parts which move with reference to each other and to fixed parts so as to form a series of chambers of changing form, each one of which when closed has constant volume, and motion conveying liquid from the suction side to the discharge side of the pump. The closed chambers move in one direction only, the parts returning with such a motion, with reference to one another, as to enclose no

liquid. In such pumps the valves are the moving walls which enclose the liquid. In the same class, also, are all pumps which consist of movable paddles fitting in a trough, or of a series of buckets mounted on a chain or a wheel.

The principal types of the second class are known as centrifugal pumps, screw pumps and turbo-pumps, in all of which the motion is communicated by one or more wheels or runners revolving in suitable chambers. In all pumps of this class the production of higher pressure in one portion of the liquid than in another portion is accomplished by the changes in the velocity of the liquid particles with reference to the passages in which those changes take place. For this reason the term "Velocity Pumps" has been taken to define the class, irrespective of the particular form of the runner, the casing, or the mechanical accessories.

In a velocity pump, the velocity of the water, measured with reference to a fixed point, undergoes first a process of acceleration in a moving passage and next a process of retardation in a fixed passage. In a water motor, or turbine, the velocity of the water, measured with reference to a fixed point, undergoes first a process of acceleration in a fixed passage and next a process of retardation in a moving passage. The production of head, in a velocity pump and in a water motor, depends essentially upon the same principles, but the same device is not equally applicable for working as a pump or as a motor, because of the distribution of the flow of water within the moving runner of the pump.

In a velocity pump, useful pressure head may be produced within the runner as well as from the velocity contained in the water when it emerges from the runner; but, in a motor, the useful pressure head cannot exceed that contained in the water originally.

In the pump, all the energy communicated to the water is communicated within the moving channels, although it may be transformed from velocity to pressure head elsewhere; in a motor, all the energy absorbed from the water is absorbed within the moving channels, though it may be transformed from pressure head to velocity elsewhere.

Pressure head can only be increased or reduced within the runner of a pump or motor when the velocity of the liquid within the runner, relative to a fixed point upon the runner, changes as the water passes through.

There can be such change only when:

(a).—The cross-section of the channel of the stream or jet within the runner varies; or

(b).—The velocity of motion of the runner varies from point to point upon the path of the stream.

The condition (a), depends upon the mechanical form of the passages within the runner; and (b) upon the kind of motion of the runner; therefore, both depend upon the particular design of the pump.

An impervious surface (Fig. 1), devoid of friction, moving in a liquid, can produce a velocity only normal to its face. It must produce a velocity equal to the component of its own velocity normal to its face, as, otherwise, the liquid would pass through the surface. The actual velocity of the liquid must be the result of the velocity of the motion of the surface normal to itself, and of some velocity parallel with the surface, not affected by its motion.

Assume an infinitesimal stream of liquid bounded by a frictionless surface which moves with reference to surrounding space. The liquid can move only along the surface.

Let u = velocity of a point on the moving channel;

v = velocity of the liquid passing that point, measured parallel with u;

w = velocity of the liquid passing the point, measured normal to u;

β = the angle that the axis of the stream presents to the direction of u and v:

Then $u - v = w \cot. \beta$ ....(I)

Let g = acceleration of gravity, 32.2 ft. per sec.;

h = head, in feet, against gravity.

If u is a velocity in a circle, let

r = distance from the center of rotation;

ω = the number of revolutions per second.

Then $u = 2 \pi r \omega$ ....(II)

The velocity of the point on the moving channel, with reference to water at rest, is u. Its velocity, with reference to the water passing through the channel at any point, is $u - v$ in one direction and w normal to u. The difference in velocity head, of water at

rest and water passing the point taken, with reference to the moving channel, is given by the equation:

$$2\,g\,h_x = u^2 - (u - v)^2 - w^2 = 2\,u\,v - v^2 - w^2$$
$$= u^2 - w^2 \text{ cosec.}^2\,\beta \quad \text{(III)}$$

This must be the pressure head produced by the motion of the channel.

The actual velocity produced in the water is v in one direction and w normal to it.

The actual velocity head produced, therefore, is given by the equation:

$$2\,g\,h_y = v^2 + w^2 = u^2 + w^2 \text{ cosec.}^2\,\beta - 2\,u\,w \text{ cot. } \beta \quad \text{(IV)}$$
$$2\,g\,h = 2\,g\,(h_x + h_y) = 2\,u\,v = 2\,u^2 - 2\,u\,w \text{ cot. } \beta \quad \text{(V)}$$

This gives the total head produced by the motion of the surface at the point taken, with reference to the head of a particle of water before it is affected by the motion.

This formula is general. It gives the total head produced by the moving passage at any point upon its surface.

Fig. 1 shows graphically the velocities considered.

$O\,A$ represents u;

$O\,C$ represents v;

$A\,B$ represents the velocity of the water, with reference to the surface, at a point on the surface;

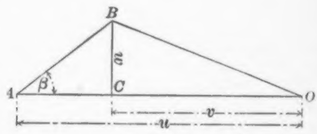


Fig. 1

$O\,B$ represents the velocity of the water, with reference to a fixed point, at a point on the surface;

$C\,B$ represents w.

We may derive the same formula by a somewhat different method, illustrated by Fig. 2.

An impenetrable, frictionless surface, or plate, presenting an angle, β, to the direction of its motion, u, possesses a velocity component, u sin. β, normal to itself, and any object in constant contact with it must have this velocity compounded with

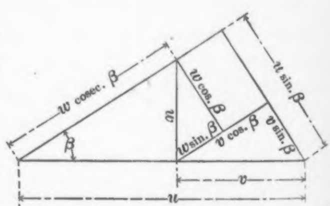


Fig. 2

some other parallel with the plate, not affected by u. If the object

moves with a velocity compounded of w normal to u and v parallel to u, we may resolve these velocity components into components parallel with and normal to the surface.

w resolves into $-w$ sin. β, parallel with, and w cos. β, normal to, the surface.

v resolves into v cos. β, parallel with, and v sin. β, normal to, the surface. Therefore, $u \sin. \beta = v \sin. \beta + w \cos. \beta$; whence $w = (u - v) \tan. \beta$; and the component, parallel with the surface, with reference to rest, is $v \cos. \beta - w \sin. \beta$.

The velocity of the surface, parallel to itself, is $u \cos. \beta$; therefore the velocity of the liquid along the surface, with reference to it, is $u \cos. \beta - v \cos. \beta + w \sin. \beta = (u - v) \cos. \beta + w \sin. \beta$.

The change in the relative velocities, of the surface and the liquid at rest to the liquid in motion, is from $u \cos. \beta$ to $(u - v) \cos. \beta + w \sin. \beta$, measured normal to the surface. The head, therefore, is determined by

$$2\,g\,h_x = u^2\,(\cos.{}^2\beta + \sin.{}^2\beta) - [(u - v) \cos. \beta + w \sin. \beta]^2$$
$$= u^2 - w^2 \operatorname{cosec.}^2 \beta.$$

Compare these formulas with those given by W. C. Unwin, M. Inst. C. E., in a paper* entitled "The Centrifugal Pump," and repeated in the article on "Hydromechanics," by the same author, in the "Encyclopedia Brittanica." Mr. Unwin's formula for the total head, in a centrifugal pump with a free spiral discharge, expressed in the symbols adopted in this paper, may be reduced to

$2\,g\,h = u_2^2 - w_2^2 \operatorname{cosec.}^2 \beta_2 + v_2^2 -$ (certain velocity heads wasted in the process of acceleration and retardation). Mr. Unwin's paper takes into consideration certain internal losses, but does not investigate the effect of unequal distribution of the flow, w_2.

Let the sub-indices 1 and 2 indicate that the characters to which they are appended represent values appertaining to particular points on the path of the same particle of liquid.

Then,

$$2\,g\,(h_{x_1} - h_{x_2}) = 2\,u_2\,v_2 - 2\,u_1\,v_1 - v_2^2 + v_1^2 - w_2^2 + w_1^2 \ldots\ldots \text{(VI)}$$
$$= u_2^2 - u_1^2 - w_2^2 \operatorname{cosec.}^2 \beta_2 + w_1^2 \operatorname{cosec.}^2 \beta_1;$$

also

$$2\,g\,(h_{y_2} - h_{y_1}) = v_2^2 - v_1^2 + w_2^2 - w_1^2 \ldots\ldots\ldots\ldots \text{(VII)}$$

and

$$2\,g\,(h_2 - h_1) = 2\,u_2\,v_2 - 2\,u_1\,v_1 \ldots\ldots\ldots\ldots \text{(VIII)}$$

* *Minutes of Proceedings*, Inst. C. E., Vol. LIII, 1877-78.

$(u_2^2 - u_1^2) \div 2\,g$ is the difference between the velocity heads of Points 1 and 2 with reference to a fixed point;

and

$(w_1^2 \text{ cosec. }^2\beta_1 - w_2^2 \text{ cosec. }^2\beta_2) \div 2\,g$ is the difference between the velocity heads of the water with reference to the plate at Points 1 and 2.

Now, let:

h_a = head produced at the orifice at Point 1, where the water enters the confining channel;

h_b = head produced in the water while passing through the moving channel from Point 1 to Point 2, the point of emergence from the moving channel and of entrance to the fixed channel;

h_c = total head produced by the runner;

h_d = head necessary to overcome all friction within the pump, including eddy currents and wasted velocities;

h_e = head available for overcoming pressure; that is, the actual lift of the water level against gravity, from still water on the suction side to still water on the discharge side of the pump.

For every elementary stream of water flowing through the pump, we have the following equations:

$$2\,g\,h_a = 2\,u_1\,v_1 = 2\,u_1^2 - 2\,u_1\,w_1 \text{ cot. } \beta_1 \qquad \text{(IX)}$$

$$2\,g\,h_b = 2\,u_2\,v_2 - 2\,u_1\,v_1 \qquad \text{(X)}$$

$$2\,g\,h_c = 2\,u_2\,v_2 = 2\,u_2^2 - 2\,u_2\,w_2 \text{ cot. } \beta_2 \qquad \text{(XI)}$$

From Formula XI, we see that the total head produced depends only upon three quantities, u_2, w_2 and cot. β_2, all of which are values at Point 2, where the moving passage terminates in the fixed passage. The angle, β, at any other point has absolutely no effect upon the head produced by the velocity changes undergone in this elementary stream. The angle, β, and the form of the discharge passages, affect the rate at which the velocity changes take place, but not the amount of those changes, and, consequently, not the total head developed when w_2, u_2 and cot. β_2 are fixed and uniform.

Ideal Pumps.

We will call an ideal pump one in which h is the same for every streamlet of water that passes through, and the friction loss, h_d, is zero, and we will investigate such a pump before considering the effect of friction.

The first, and the simplest, case to be considered is where there are an infinite number of elementary frictionless passages of exactly similar form and position with reference to u. u_2, w_2 and cot. β_2, therefore, are uniform.

Let Q = quantity of water pumped per second;

A_2 = total area of the passages normal to w_2;

$$w_2 = Q \div A_2 \quad \text{.......... (XII)}$$

$$\text{and } \frac{Q}{A_2} = \left(u_2 - \frac{g\,h_c}{u_2}\right) \tan.\ \beta_2 \quad \text{.......... (XIII)}$$

gives the discharge for every possible head; and the form of the vanes at other points than their tips is of no importance. This is a limiting case.

The other ideal cases in which we are interested are those where there are a limited number of vanes of similar form. In these cases, the values of u_2, w_2 and β_2, between the vanes, do not necessarily correspond with their values at the vanes. Before these quantities can be known mathematically at all points, we must obtain two more equations expressing relations between them.

If $u = u_1 = u_2 =$ constant, and h_c is constant, w_2 cot. β_2 is constant; but w_2 and cot. β_2 may vary, and, until their relation to one another is known, the relation between h_c and Q cannot be known.

If $u = 2\,\pi\,r\,\omega$, we have all three variables to consider.

In any case, the value of $2\,u_2\,v_2 = 2\,u_2^2 - u_2\,w_2$ cot. β_2 for each streamlet is the maximum value of $2\,u\,v$ for that streamlet, but we may, for convenience only, consider u and cot. β as constant for all streamlets, and that the values of these quantities are the same as at the tips of the vanes. Designating those values by capital letters, our formula becomes:

$$g\,h_c = U_2^2 - U_2\,W_2 \text{ cot. } \beta_2 \quad \text{.......... (XIV)}$$

in which h_c and W_2 are the only variables, so that if either one is known the other can be found.

The mathematical problem of determining the relation between head and discharge with any form and number of vanes is too complicated to admit of general solution; but we may obtain approximate solutions in some cases, and we may also learn how to proportion the vanes so as to make the flow as uniform as possible.

Consider an impenetrable surface moving in the direction of u and totally immersed in water which is undisturbed except by the

motion communicated to it by the surface. The relative motions of the surface to various particles of water will be the same as if the surface were fixed and the water moving with a velocity,—u, as a whole. The disturbances which would be caused in the uniform flow of the water by the surfaces under these conditions will be the same as those produced in otherwise quiet water by the motion of the surface.

If the surface is a plane normal to the direction of u, the deflections of the flow will be somewhat as shown in Fig. 3, *a*. If the surface is a plane presenting an angle, β, to the direction of u, the deflections of the flow will be somewhat as shown in Fig. 3, *b*. If the surface is a section of a cylinder with its axis normal to u, the deflections of the flow will be somewhat as shown in Fig. 3, *c*. In all these cases there is a certain space on the side of the surface (marked x in the figures) where the water follows the surface, or does not join in the flow of the remainder of the water, although it is disturbed by its passing by. This protected water moves in two closed currents or eddies, which are kept in motion by friction with the water that is passing. If one edge of the surface points in the direction of u, the deflection will be somewhat as shown in Fig. 3, *d*, in which the corner of one eddy is moved along the surface. These figures are for illustration only, and no attempt has been made to make them represent the conditions which actually obtain quantitatively for any particular surfaces or velocities. The sketches are limited to only two dimensions, it being assumed that the body of water is bounded in the third dimension by parallel surfaces, and that there is no motion in the third dimension.

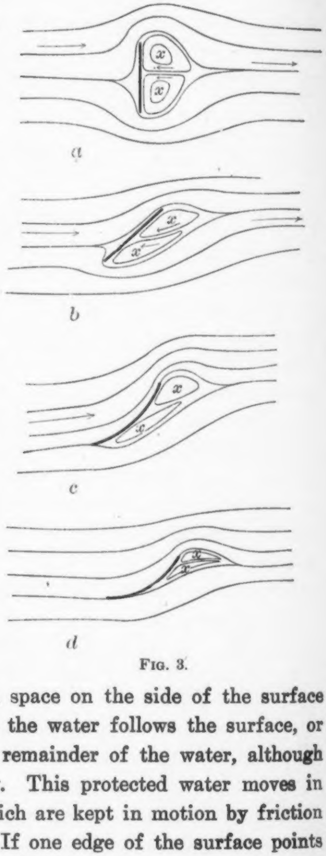


FIG. 3.

These sketches illustrate the fact that near the surface the velocity of the liquid is modified more than at some distance from it. Consequently, if our equations for head hold strictly for the element of liquid which is in immediate contact with the surface, the equations for those elements which are not in immediate contact will give less values for the same head.

If, instead of a single surface, we have several similar surfaces moving with the same velocity, and arranged so that all the water being considered must pass between some two of them, there is a limit placed to the distance which any particle may have from the forward moving surface of any vane, when passing through.

Fig. 4, *a, b,* and *c,* illustrate the action of a set of vanes mounted around a shaft with their axes normal to the shaft, revolving in a cylinder of annular section. The diagrams show both plane and curved vanes, the curved vanes presenting such an angle, β_1, to the direction of motion as to permit the water to enter the space between them without shock, that is, $w_1 = u$ tan. β_1. The production of v is gradual, in this case, while, in the case where the vane is not curved, v is produced suddenly at the entrance next to the vane, and very gradually at some distance from it. The result is very evident that the flow is more concentrated at the surface of the vane than at some distance from it, in each case; but, that in the case where v is produced the most suddenly the flow is most concentrated. The eddy, x, disappears when the flow fills the passage entirely at both entrance and exit to the passage, which can only be in the ideal case of an infinite number of vanes. When the discharge is positive the point of the eddies extends in the direction of the flow, which is against the pressure developed by the pump; but if the pressure against which the pump is developing pressure is so great that no water is pumped in that direction, and the water flows back through the pump, the point of the eddies extends in the direction of the flow, which is negative. If the pump is not discharging any water in either direction the eddy closes the passage completely, somewhat as shown in Fig. 4, *c.* The energy taken by the pump in this case is that necessary to overcome the internal friction of the liquid, eddies within the runner and immediately above and below it, and, as we are now dealing with an ideal liquid, that is zero. The velocity of the water above the runner, that is, on the high-pressure side, is dis-

turbed by eddies also. In these illustrations a deflection of the direction of the stream as a whole is shown, while in the illustrations in Fig. 3 only a temporary displacement by the surface is shown, the pressures generated being allowed to force the water

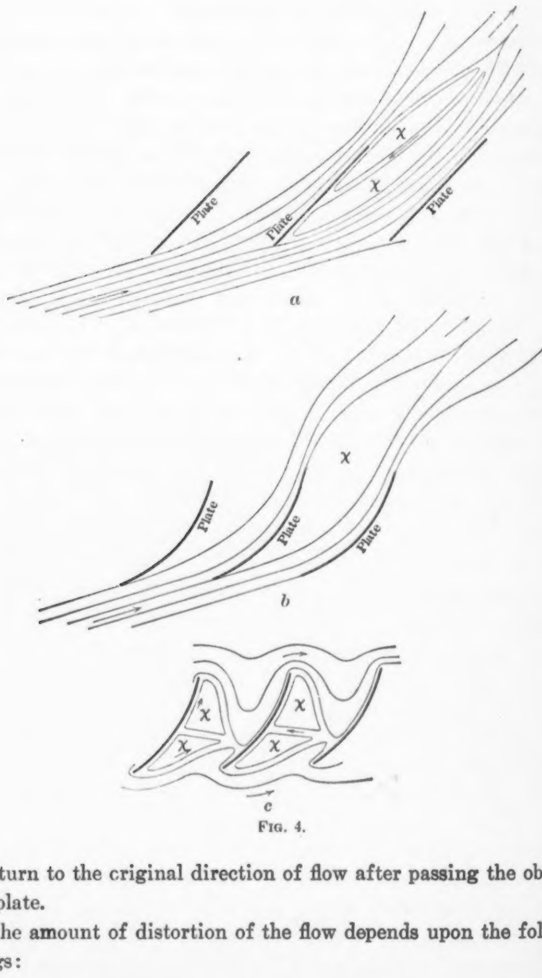


FIG. 4.

to return to the original direction of flow after passing the obstructing plate.

The amount of distortion of the flow depends upon the following things:

First, the distance of the water in the channel under consideration from the forward moving surface of the vane acting upon it. This can only be made small by making the vanes close together, which implies that there shall be many vanes. The more vanes the less the distortion.

Second, the total amount of the velocity, v_2, communicated to the water. As the head produced depends upon the product, $u_2 v_2$, v_2 can only be small when u_2 is large. The smaller the value of v_2, the less the distortion.

Third, the rate at which v is communicated to the liquid. In order that the distortion may be minimum, the rate of production of the velocity, v, should be uniform, as any departure from uniformity tends to increase the distortion of the flow. Therefore v_1 should be 0, and the rate of acceleration of v, from entrance to the moving channel to emergence from it, should be uniform, and as slow as possible. This implies that the rate of flow through the pump should be as slow as possible.

We are limited in the number of vanes by the friction they cause as well as by the obstruction they place in the space available within the runner by their bulk. If we combine the second and third conditions just set forth, we see that the vanes should present a small angle, β, to the direction of motion, and that their actual form can be determined with considerable precision for the condition of maximum efficiency, for any value of w_2 at the edge of the vane. This maximum value of w_2 will still be greater than the mean value of w_2.

It is impossible to design a vane which will give uniform acceleration to the water at different discharges. We can only make the acceleration uniform in contact with the vane at one particular discharge. Therefore, if a pump is designed for the highest efficiency at some particular head and discharge, it cannot produce as good efficiency at any other head and discharge. We may design a vane, however, so as to obtain uniform acceleration in the direction of v, if we know w at all points. In the case where w is uniform:

Let l = distance from Point 1 to Point 2 in the direction of w;

t = the time taken by a particle to traverse that distance;

s = distance moved by the particle in the direction of v.

Then $l = w\,t$.

If the acceleration producing v is uniform, it is $\frac{v_2}{t} = \frac{v_2\, l}{w}$; and the value of V at any instant, t_x, after the water enters, is

$$V_x = \frac{V_2\, t_x}{t} = \frac{V_2\, l_x}{l}.$$

$U_x - V_2 \frac{l_x}{l} = w \cot. \beta_x$; whence, if the relation between U_x and U_2 is known, cot. β_x is known.

$s_x = \frac{V_x\, t_x}{2} = \frac{V_2\, t_x^2}{2\, t} = \frac{V_2\, l_x^2}{w\, l}$; from which the actual path of the particle can be plotted.

If the relation of U to l is known, the path of the particle with reference to the vane (that is the form of the vane) can be plotted also. U is ordinarily either uniform or equal to $2\, \pi\, r\, \omega$. If U is uniform the abscissas are $U\, t_x - s_x = l_x \left(\frac{U}{w} - \frac{V_2\, l_x}{w\, l} \right)$; and the ordinates are l_x. If $U = 2\, \pi\, r\, \omega$, the abscissas are

$$\frac{(r_x - r_1)}{w} \left[2\, \pi\, \omega\, (r_1 + r_x) - \frac{V_2\, (r_x - r_1)}{r_2 - r_1} \right];$$

and the ordinates are $(r_x - r_1)$.

w is not constant in most cases. In screw pumps U is constant but w_2 is greater than w_1. In most centrifugal pumps, w_2 is less than w_1. The acceleration producing v should be uniform with reference to time, not space; hence the proper curvature of the vanes cannot be determined, except in the cases where all the values of w are known; but it may be determined approximately when w_1 and w_2 are known, upon the assumption that the acceleration (or retardation) in w is uniform.

In that case $\frac{w_1 + w_2}{2} = \frac{l}{t}$, and the acceleration is $\frac{w_2 - w_1}{t}$

$$= \frac{w_2^2 - w_1^2}{2\, l}.$$

$$w_x = w_1 + \frac{(w_2^2 - w_1^2)\, t_x}{2\, l} = w_1 + (w_2 - w_1)\, \frac{l_x}{l};$$

$$l_x = \frac{(w_1 + w_x)\, t_x}{2}; \quad t_x = \frac{2\, l_x}{w + w_x};$$

$$v_x = \frac{V_2\, t_x}{t} = V_2 \frac{l_x\, (w_1 + w_2)}{l\, (w_1 + w_x)};$$

$$s_x = \frac{V_x\, t_x}{2} = \frac{V_2\, t_x^2}{2\, t} = \frac{V_2 l_x^2\, (w_1 + w_2)}{l\, (w_1 + w_x)^2} = \frac{4\, V_2\, l_x^2\, (w_1 + w_2)\, l}{[2\, l\, w_1 + l_x\, (w_2 - w_1)]^2}$$

$U_x - V_x = w_x \cot. \beta_x$ becomes

$$U_x - V_2 \frac{l_x (w + w_l)}{l (w_1 + w_x)} = w_x \cot. \beta_x \ldots\ldots\ldots\ldots\ldots\ldots (XV)$$

Formulas hitherto given may be applied to a water motor as well as to a pump, by considering those cases where v is greater than u (in which case w is negative). In a pump v is less than u; in a motor or turbine v is greater than u.

In a water-wheel in which all the available energy in the water is reduced to velocity in the fixed passage, $2 g h_c = v_2^2 = 2 u_2 v_2$; whence $2 u_2 = v_2$, and $w \cot. \beta = u$; the well-known condition of highest efficiency in impulse wheels, not in wheels in general. In other water-wheels, pressure is consumed within the runner, as well as upon impact.

In a pump, when $u_2 = 2 v_2$, $2 g h_c = w_2^2$ and $w_2 \cot. \beta_2 = v_2$.

Friction Head.

The head, h_d, or friction head, is that required to overcome the losses within the pump and its auxiliary passages, which must be overcome in order that the flow, w, may take place. It must be supplied from the total head, h_c, leaving an effective head, h_e, to produce difference in level, or velocity, or both combined, between the discharge side and the suction side of the pump.

$$h_e = h_c - h_d \ldots\ldots\ldots\ldots\ldots\ldots (XVI)$$

A liquid moving in a straight channel (of uniform section) is acted upon by the walls of the channel, which retard those particles in immediate contact with them. This retardation depends upon the adhesion between the water and the channel. This retardation is usually considered as independent of the pressure, and, in channels made of the materials commonly used, of the usual roughness, containing water flowing at moderate velocities, this assumption is admissable. But the particles of liquid which are not in immediate contact with the confining walls are affected by those which are, so that the frictional disturbance extends itself throughout the liquid stream.

If the stream be in a straight pipe of circular section, the particles in the center will move fastest, and those against the pipe slowest. The distribution of the velocities depends upon the relative friction of the liquid particles against one another, and their

friction against the pipe; that is the relation between cohesion and adhesion. We call that property of a liquid which causes internal friction, viscosity.

If a liquid moves in a passage of variable form, as in an enlarging or contracting pipe, or a bend in a pipe, some of the particles of liquid not only move faster than others, but also change the relation of their velocities to others. This also causes internal loss, which consumes head, because of the viscosity of the fluid.

If a stream starts from rest, flows through a channel of a pump and is brought again to rest, we have to consider all the friction losses undergone by it, and deduct them from the total head produced, in order to find the useful head.

In general, these losses are as follows:

1.—Friction loss in the flow of the water, from rest to the highest velocity at the entrance to the moving passage. This must not be confounded with the velocity head at the entrance to the vanes. The suction passage is from a basin of infinite size to the suction opening of the vanes, and this loss consists of the following portions:

a.—Entry Head.—This is equivalent at most to about half the velocity head within the suction pipe, caused by the internal friction within the stream between the points in the suction basin where the velocity begins and a point in the center of the pipe about three diameters of the pipe distant from its suction end. If the proper bell-mouth or funnel-shaped passage is placed at the suction end of the pipe this lost head may be reduced to as little as 3% of the velocity head, with very smooth pipes.

b.—Friction Head Proper.—This may be calculated by the use of formulas for any quantity and any size of pipe. If the passage is not circular, it can be calculated approximately, in almost every case, by an adaptation of Kutter's formula.

c.—Loss in Head Due to Bends in the Passage.—These can be obtained, approximately, for circular pipes, from well-known formulas and tables, and, for special forms of passages, it can be determined, with sufficient accuracy for practical purposes, by analogy.

2.—Friction loss in the flow of the water through the moving passage, as follows:

d.—Friction Head Proper.—The stream moves between the forward moving surface of the vane and the eddy behind the adjacent

vane with a velocity of w cosec. β, which is a variable quantity. This loss cannot be calculated accurately from known formulas, because the form of the stream is not known accurately; but a working approximation can be made by applying Kutter's formula, considering the wet perimeter as the perimeter of the passage at some radius less the width of one vane. More accurate approximations may be used in particular cases. This loss is usually one of the largest in the pump.

e.—Loss in Head due to Viscosity in the Production of v, and to Modifications in the Direction and Intensity of w.—These losses are often exceedingly great. In order to make them small, the pump should be designed in accordance with the principles hitherto laid down. If w changes in direction, the loss due to its change can be calculated approximately in some cases, and in some cases it can be determined, with sufficient precision, by analogy to the known losses due to bends in circular pipes.*

3.—Friction loss in the flow of the water through the pump casing and discharge pipe to rest in the discharge basin.

f.—Loss in the Vortex due to Viscosity of the Water, Independent of the Friction with the Casing.—If the vortex chamber is large, and w_2 bears a fair proportion to v_2, this loss is small. If w_2 is very small, this loss may be a large percentage of the total loss. The amount of this loss depends to a great extent upon the form of the vortex chamber, and also upon the form and size of the eddies behind the vanes which protrude into it.

g.—Loss in Friction in the Vortex Chamber Due to the Presence of the Casing.—This cannot be separated entirely from the loss, f, but in a properly designed pump it may be very small. It may be calculated in some cases. These losses (f and g) will be considered in connection with a consideration of the best form of casings for centrifugal pumps.

h.—Friction Loss in the Discharge Pipe.—If the pipe is properly connected to the casing, this loss can be calculated by well-known formulas.

i.—Loss in the Discharge Basin.—If the discharge pipe enters

* It should be noted here that, if the suction pipe is long, and connects directly to the opening of the vanes, the effect of friction is to cause a definite relation between the velocity in the center of the pipe and that at other points, the mean velocity being about eight-tenths of that in the center. This fact fixes the most desirable values of w at various points on the suction opening on pumps of ordinary types; and the intake should be designed with this fact in view.

the basin well below the water surface, and the basin is infinite, this loss may be made very small, by extending the pipe into the basin so that the eddies formed by the emerging water will not cause a contraction of the stream; or by enlarging the pipe near the end into a funnel-shaped discharge. The velocity head in the water is thus converted almost entirely into pressure (see Appendix I); but, in case the arrangement is such that none of this velocity in the discharge pipe can be regained it must be considered as a loss.

Each one of these losses depends upon the velocity of the water in the passage considered; and all vary when the discharge varies, but in different ratios. Our total friction head, h_d, therefore, is a function of Q, but a very complicated one. We may calculate approximately each one of these losses at normal discharge if all values of w are known.

There is always disturbance within the water enclosed by the vanes (see Fig. 4) whenever there is any head produced. Consequently, h_d cannot be zero. It has actually a minimum value, at a certain head, h_{c_x}, and it increases as h_c increases or diminishes from h_{cx}.

In addition to these friction losses, which may all be treated as consuming head, there are also the following losses to be considered in any pump that contains a rotating runner:

1.—Loss in power due to the friction of the bearings and stuffing-boxes.

2.—Loss in power due to friction between the moving parts with water not flowing between the vanes.

3.—Loss in quantity pumped due to water leaking through the joints from the discharge side to the suction side of the runner.

In the consideration of any class of pump we must note, not only the head produced, but also the character and amount of the losses, of all kinds, in the class studied, and in its various types.

SCREW PUMPS.

Screw pumps form the simplest class of velocity pumps. A screw pump consists of a screw, propeller or spiral surface or surfaces revolving around a central shaft in an annular cylinder, with or without auxiliary devices. Considering first the case where

there are no auxiliary devices, we have merely a propeller of some kind revolving in a section of a pipe of uniform diameter. In this case the velocity, v, is parallel with the perimeter of the pipe, and there are no means of converting it into head as long as it is confined to the pipe of uniform diameter. If the discharge pipe is of great length, all the velocity, v_2, is consumed in friction with the sides of the pipe, and is entirely lost, as far as useful work is concerned. The useful head then becomes h_e, where

$$2\,g\,h_e = h_c - h_d - v_2^2 = 2\,u_2\,v_2 - v_2^2 - h_d$$
$$= u_2^2 - w_2^2 \cot.^2 \beta_2 - h_d \ldots\ldots\ldots\ldots (XVII)$$

in which h_d is practically what it would be if v_2 were not dissipated in friction; but, as power is consumed in producing v_2, the efficiency is less when v_2 is not reconverted into head.

In a screw pump, u is constant as long as r is constant, and as w is parallel with the axis of the pipe, u is evidently constant at each point on the path of each elementary channel of water. But those channels of water which are nearest to the shaft are affected by smaller values of u for $u = z\,\pi\,r\,\omega$. Consequently, we must have different values of w_2 cot. β_2 at each radius. h_f also varies when the radius varies.

As w_2 cot. β_2 cannot be less than 0, the pump cannot produce a head greater than $\frac{u^2}{2\,g}$. $2\,g\,h_c = u_x^2 = (2\,\pi\,r_x\,\omega)^2$ gives the smallest radius at which the pump can produce sufficient head to overcome the opposing pressure, losses being neglected. Therefore, from this radius, or a larger one, to the shaft, the pump should be closed so that water cannot flow back through the pump in the area contained within it.

We see also that, as the radius diminishes, the quantity, w_2 cot. $\beta_2 = 2\,\pi\,r\,\omega - v_2$, also diminishes; therefore, v_2 must increase. When $u = v_2$, and v_2 is lost in friction with the pipe, there is no useful work. In pumps of this type, therefore, it is necessary that v_2 should be as small as possible, and that, in consequence, u shall be very large in proportion to the effective value of $2\,g\,h_c$. This is likely to involve considerable friction of the vanes with the water flowing through the space between them, on account of the high velocity of flow. It is necessary in this case to make the vanes as short, as smooth, as far apart, and as thin as possible, in order to keep the friction within rea-

sonable limits, even though this may involve some sacrifice in the uniformity of w_2. The angle, β_1, should be such that the water will enter with as little shock as possible, and the curvature should be determined with the greatest care, as the rate of production of v is likely to be very rapid, although its total amount is small.

Pumps of this class are at a great disadvantage when the head pumped against varies exceedingly, and especially when the value of v_2 at the smallest radius at which the water is permitted to emerge from the pump is high. When the opposing head varies, the distribution of the flow within the pipe varies exceedingly, w_2 increasing more rapidly at smaller radii as the head decreases, and decreasing more rapidly as the head increases.

In screw pumps it is not necessary that the head contained in the velocity, v_2, be lost. It may be regained by the use of a vortex chamber of sufficient size, or by the use of deflector plates mounted in the discharge pipe at such angles and with such curvatures that the velocity, v_2, shall all be turned into the direction of the pipe and reduced to zero. The vortex chamber is very useful at all discharges, while the deflector plates can only be designed for high efficiency at a particular discharge, as they act upon the water in a manner similar to that in which the vanes act, and produce eddies and friction losses, as the vanes do.

In case deflector plates are used, the formulas already developed for the vanes may be applied to the plates, with proper consideration for the fact that u is not the same at various radii.

If we designate by φ the angle that the plane presents to the direction of $-v_2$, we should make $v_2 = w_2 \cot. \varphi_1$, and $\cot. \varphi_2 = 0$. Then, for the ideal pump, v_2 is all regained in the form of head. In the real pump all the head is not regained, as the value of w_3 emerging from the deflector plate is higher than that of w_2. Deflector plates, therefore, are not desirable unless there is no other method of converting v_2 into head that can be applied to the case under consideration, and unless the head contained in v_2 is of considerable importance.

The most efficient vortex chamber that could be devised is an infinite body of water. When it is possible to allow the runner to discharge directly into the discharge pool without the intermediary of a discharge pipe this method should be adopted. The water then follows free vortex lines, and the only head lost is that due to the viscosity of the liquid. Viscosity of a liquid is of such a nature

that this loss is least when the volume of water in which any internal disturbance expends itself is greatest.

Where it is impossible to discharge directly into a large basin, a casing of some form must be used to collect the water discharged in various directions from the runner and direct it all in one direction into the discharge pipe. This process of changing the direction of the various streamlets may be accompanied by a process of retardation of the actual velocity of the water, or may not, as conditions demand. If the velocity is not retarded in the collecting chamber it may be retarded in the passage from the vortex chamber to the discharge basin, or in the discharge basin itself. The head contained in the water where the retardation commences may be transformed from the form of velocity to that of pressure very economically in a passage, the axis of which is straight, and there are many cases where it is better not to reduce the velocity of the water in the pipes to a very small value, because of the size of the pipe which would be required to carry the necessary quantity. The size of both the suction pipe and the discharge pipe should be determined upon considerations of economy, which have nothing to do with the amount of water or the velocities in the pump proper, although the head necessary to overcome the friction of these pipes must be included in that produced by the pump. The best size of pipe to use should be determined in the same way as the proper size of wire to use in an electric transmission line. The total cost of the pipe line plus the total value of all the power lost by friction in it should be a minimum. If the installation is a permanent one, this reduces to a very definite relation between the cost of the pipe, the interest on the money invested; and the cost of power per year.

Centrifugal Pumps.

Centrifugal pumps are those in which the water enters the runner parallel with the suction pipe and is discharged in all directions normal to the suction pipe. There are many types. The vanes may extend to the opening into the suction pipe, in which case there will be a different value of r_1 and u_1 for every elementary stream; or they may commence at some distance, r_1, from the shaft and extend to a distance, r_2, from it, which may be the same for every particle of water that follows the surface of the vane. If

r_1 and r_2 are uniform for all particles in contact with the vanes, the flow, w_2, will likewise be uniform for all such particles, unless there is greater loss, h_d, for some particles than for others, owing to the path they traverse from the suction pipe to the outer end of the vane.

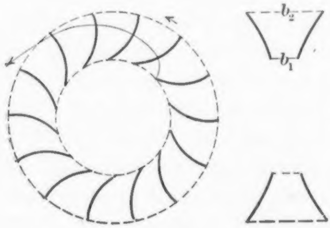


FIG. 5.

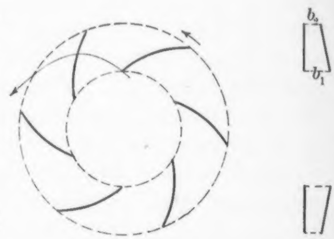


FIG. 6.

The vanes may be curved forward from r_1 to r_2, as shown in Fig. 5, or they may be curved backward, as shown in Fig. 6. In Fig. 7 the path of a particle from r_1 to r_2 is shown, (a) where the discharge is such that water enters the space between the vanes without shock, (b) where the discharge is excessive and the head low, and (c) where the discharge is less than normal. The figures make no attempt to show the actual path of the particle in any particular design, as they are merely for qualitative comparison.

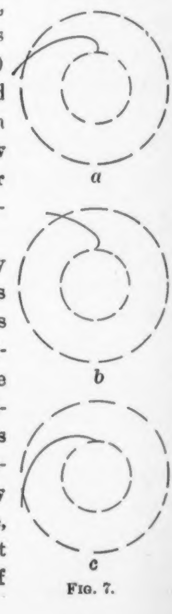


FIG. 7.

The width of the space between the vanes may vary likewise. It may be uniform from r_1 to r_2, as in the most common types of pumps with runners consisting of blades revolving in a casing of uniform width. Making the width of the space between the casings uniform has many mechanical advantages. The space between the vanes may contract from the suction side to the discharge side, so as to maintain an approximately constant value of w from entrance to discharge, as is done frequently in dredging pumps, or it may widen so as to produce a very small value of

w_2. In order to secure uniform acceleration of the water to produce v_2, the relation between the width of the vanes and the curvature of the vanes at various points must be determined carefully for each type.

The sources of loss of power which do not affect the head produced by the pump are:

1.—Friction of bearings and stuffing-boxes.

2.—Friction of the pump parts with water moving in other directions than through the space between the vanes.

The first of these is purely mechanical; and the second can be treated as such. It is often one of the greatest losses in the pump.

The sources of loss of power which appear as consuming head produced by the pump are:

3.—Friction of water passing between the vanes.

4.—Loss in reducing the velocity of the water to zero in the pump casing, discharge pipe and discharge basin.

5.—Loss due to friction in such part of the suction and discharge pipes as are considered part of the pump.

The problem of pump design is to minimize all losses and obtain at the same time the discharge and lift desired; also to make the pump as efficient as possible when the conditions of discharge are different from those at which the best results are obtained, and to make it regulate automatically to meet the various conditions found in the actual operation. We will consider how these losses are affected by the pump design.

1.—*Friction of the Bearings.*—This can only be overcome by good mechanical design and by relieving the bearings of all unnecessary weight. To do this the rotator should be as light and as well balanced as possible, and the weight of the water should not be carried on the runner. In pumps with horizontal shafts, the thrust of water on the bearings can be avoided entirely by giving the pump a double suction, as shown in Fig. 8. Pumps mounted on vertical shafts may have their bearings relieved of some of the weight by partially exhausting the pressure in the casing above the runner. This increases the leakage, as it implies an upper as well as a lower joint, which is usually avoided in pumps mounted in the vertical position.

2.—*Friction of the Pump Parts with Water Moving in Other Directions than Through the Spaces Between the Vanes.*—With

shrouded runners, this can be reduced by excluding the water from the space between the runner and the casing, as in Fig. 10, or by removing it thence when it leaks in. For pumps mounted on vertical shafts, the introduction of air under pressure may accomplish this in part. Another method of getting rid of this loss almost entirely is shown in Fig. 9. It consists in allowing the water to flow freely around the runner, at the same speed as the pump. The figure shows the runner immersed in a large open pit or reservoir. The same method can be adopted if an enclosed pit is used, but it is not as efficient, as the water has friction against the sides of the pit.

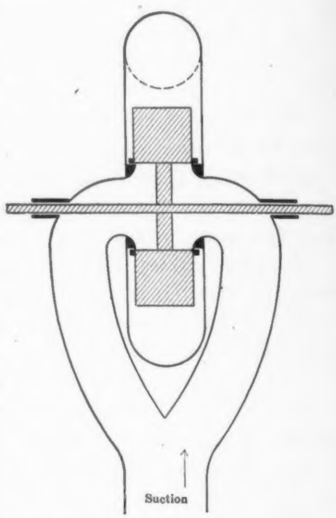


FIG. 8.

3.—*The Friction of the Water Flowing Between the Vanes.*—This has already been discussed.

4.—*Loss in Converting the Velocity Produced by the Runner into Head.*—In order that the velocity in the water may be reduced to zero, we must enlarge the passages in which it is flowing, the enlarged section being measured normal to the direction of flow. How this is to be done depends largely upon the purpose to which the pump is to be put and the velocity which is to be reduced. If the

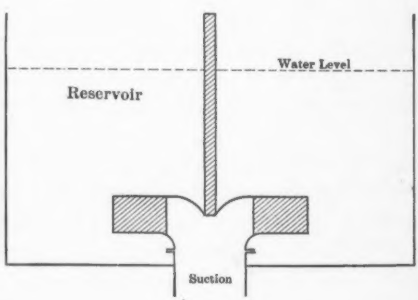


FIG. 9.

pump is to discharge through a long pipe at a comparatively high velocity, there is no advantage in reducing the velocity to a lower mean that that to be used in the pipe. Moreover, long, large pipes are expensive, and it is often advantageous to use smaller pipes and higher velocities, even for short discharges, and recover the head in the reservoir or discharge basin. Therefore, we may consider two extreme cases, namely, where the velocity is reduced to a small value before entering the discharge pipe, and no subsequent effort is made to regain any of it in the form of head, as in the case of a dredge; and where the velocity in the discharge pipe is the same as the mean velocity in the pump at the periphery of the runner. In either case, it is desirable to have a vortex chamber of ample size, to allow the effect of the pulsations at the tips of the vanes to be dissipated, to as great an extent as possible, before the water enters the discharge pipe; but, in the case where the velocity of discharge is highest, the casing can be much smaller than in the other case. There remains also the case, shown in Fig. 9, where there is no casing at all, which, of course, is the most efficient, as has been pointed out before.

Where a casing is used to restrain the water, it must be designed so as to allow uniform retardation of the velocity at all points at any given distance from the center until the required velocity is assured, and then to collect the water from various points on this circumference into one direction of flow. The spiral-shaped casing should not come very close to the runner, and its curvature should be calculated for the purpose just mentioned, and not with any view to modifying the velocities at any point, except as regards direction.

There are two general forms of casings, and intermediate forms between these general or extreme forms. The first is shown in the diagrams, Figs. 8 and 10. This form of casing is of uniform width and of about the same width as the runners. The water, upon entering it, increases its radial rate of flow in proportion to its tangential flow. It does not spread

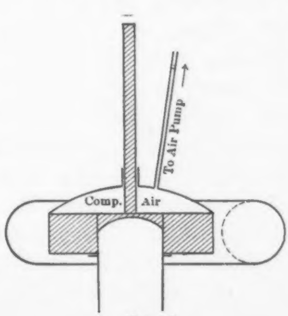


FIG. 10.

out laterally at all, as the casing is not wide enough. To use this design, the vanes must be much wider than is requisite to allow the water to enter without unnecessary loss, and, while in certain cases this is an advantage, it is not always so, as will be shown later; or, if the vanes are not of extra width, the discharge pipe must be oval in cross-section where it joins the casings, and round out as it leaves the pump. There would be some advantage in this for certain kinds of pumps, especially dredges, but the writer has not seen the method tried. The usual method of constructing casings is somewhat as shown in Fig. 11, in which the casing widens out as it leaves the tips of the runners. If the velocity of the water as it emerges from the runner is fairly uniform, there should be but little loss in a casing, if it is properly designed.

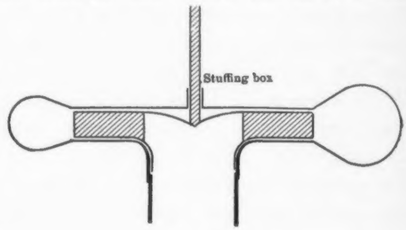


FIG. 11.

5.—*Loss in Friction in the Suction and Discharge Pipes.*—These losses, usually, can be calculated to a close degree of approximation by well-known formulas. In the case of long pipes, the heads necessary to overcome these losses are very great, and must always be taken into consideration in the design of a pump, whether or not they are considered as chargeable against it in determining the efficiency.

6.—*Leakage around the Runners from the Discharge Side to the Suction Side.*—Some leakage must always be allowed for, especially if the pump be small and the head high. The only cure for leakage on one side of the runner is close-fitting joints of large face. On the other side there need be no leakage if the pump has not a double suction, as leakage can take place only at the joint. All propositions looking to the exclusion of the water from the space between the runner and the casing near the joint involve the necessity of two joints, with water at different pressures outside of them. They cannot possibly prevent leakage. Air pressure may be introduced into such a space, but the result is, not to prevent leakage, but to diminish friction. When air pressure is introduced,

the leakage still takes place, but the water does not keep the space full, merely running through the joints and following the surfaces of the casing or the rotator from one joint to the other.

In the preceding, certain losses have been spoken of as friction losses. This term has been used for convenience only, and not with a view to identifying hydraulic losses with mechanical friction. The losses are thermodynamic in character, and it makes no difference, in practically considering them, whether or not the the thermodynamic process of reducing the heterogeneous motion to heat has been entirely completed within the pump, if the velocities considered are no longer available for useful pumping after the disturbances considered have been initiated.

In the practical design of a pump, there are mechanical considerations which fix certain dimensions of the design within comparatively narrow limits. These are the sizes of the suction and discharge pipes, and the velocity of rotation.

If we make the angular velocity very small the pump is necessarily very large indeed, and expensive in proportion, as are, also, the machinery necessary to drive it and the foundations necessary to set it. If we fix the angular velocity, in order to use some particular engine or motor, we thereby fix the value of u_1. The other dimensions of the design can then be determined without further reference to the source of power. If the floor space is very limited, small casings and small discharge pipes should be used, and the head regained in the discharge pool or reservoir, or by enlarging the pipe sections at some point where there is no lack of space; but, if the pump has plenty of room for its setting, the runners may be longer, curve backward at a small angle to the direction of rotation, and be very few in number; and the casing may be large, or may even be dispensed with altogether, as in Fig. 9.

The catalogues of the various pump firms manufacturing centrifugal pumps at the present time demonstrate the fact that there is a great variety of design in the pumps now on the market. Some pumps have wide vanes, others narrow; some have runners which become narrower as the radius increases, others are of uniform width; some have very great curvature to the vanes, others slight; and the varieties of forms of casings are equally numerous. No element of design is meritorious unless combined with other suitable elements, and there are many pumps which are excellent which have

quite dissimilar appearances. For each type there is a most perfect proportion for each size; and some types are more adapted for special kinds of service than others. Each pumping problem demands consideration by itself, and, while certain parts, such as casings, bearings and elbows, may be used for many different conditions, if these are fixed, the runner proper must be designed especially for each particular service, if really efficient results are to be obtained.

A few remarks concerning the requirements of particular kinds of service may be opportune.

The requirements for dredging are peculiar and severe. The pump must discharge anything that will enter its suction pipe. This demands that every passage within the pump must have no cross-section less than that of the suction pipe. Material must be kept in suspension in the water during its passage through the pump. This demands that the velocity of flow through every passage, including the casing, shall not be less than a certain amount. The parts must be strong enough to stand the impact of heavy, solid matter, such as boulders, and hard enough to stand the wear of sand and grit contained in the water. The wearing parts should be replaceable. The head must be high, and it is subject to considerable variation if the length of the pipe to the spoil bank varies. The velocity of discharge is not regained, and it is as great as the velocity in the suction pipe, as a rule.

The requirements for pumping sewage and drainage admit of higher efficiency. There are practically no special conditions limiting the efficiency of the design except the available space and time.

Centrifugal pumps may be used for pumping water to considerable heights. The limiting factor in the head pumped against is the high peripheral speed necessary to throw the water to great heights. We have seen how the head cannot under any circumstances exceed the height, $\frac{u_2^2}{g} = h$. When it is necessary to discharge against higher heads than are consistent with safe peripheral speeds limited by the equation just given, it is necessary to use more than one pump, or a pump with several sets of runners.

The effect of variation of speed upon pump regulation requires mention. To obtain maximum efficiency, the pump must operate

at the speed and against the head for which it is designed. If it is designed correctly it will then throw the quantity of water for which it was designed. If the opposing head remains constant and the speed falls off, the discharge will diminish and the losses increase, while, if the speed remains constant and the opposing head increases, the same result will follow. On the other hand, if the speed increases or the head diminishes, the discharge will usually increase, but the efficiency will still diminish. For every speed there is a certain discharge at which the entrance losses will be a minimum, and a certain head which corresponds to that discharge, but any variation in speed implies a variation in both head and discharge to obtain the best results, and, in consequence, any attempt to make a pump discharge a certain quantity of water at a certain head, merely by varying the speed until the discharge is secured, because the pump is rated as of a certain capacity in discharge, is likely to be extremely wasteful.

Multiple Runner Pumps.

It is evident that a number of runners with deflector plates between them may be arranged in a series, or that a number of centrifugal pumps may be arranged in a series. The same principles apply to each set of runners as to a single pump. Pumps with several sets of runners have been built successfully for high head, and they are usually called "turbo-pumps" on account of their similarity to steam turbines, to which they have been direct-connected and operated at high speeds. The principles of design indicate that pumps of this type, as well as the centrifugal and other types, can be built for successful service for water-works purposes to compete with the types ordinarily used for such service, and perhaps they will soon be built for this purpose to the exclusion of reciprocating pumps. The present difficulties are not of an essential nature, but it appears that, up to the present time, there has been little effort in this direction, just as, up to the present time, the steam turbine has received but little development as a competitor of the reciprocating engine. The design of a pump is a thermodynamic problem, like the design of a steam engine, but a simpler one because of the incompressibility of the liquid.

Losses in Elbows and Bends.

In developing a general theory of design applicable to all types of velocity pumps, the losses and disturbances occasioned by the passage of the water around bends in the piping system have been disregarded. In practice, these losses are very important, and must receive careful consideration.

In a centrifugal pump, besides the losses in the piping and the bends leading to the suction opening of the pump proper, there is a loss in changing the direction of the flow from parallel to normal to the axis of rotation. The amount of this loss depends upon the design of the runner. There is also a loss in the vortex within the casing, which depends upon the form of the casing.

The following general principles may be followed with profit:

Bends in the water channels should be formed so that water in traversing them moves in a free vortex, in order that the loss of head within the stream due to the bend may be a minimum.

There are too many possible designs of pump passages to permit of the use of any general equation for calculating the losses of head in them in every case. The losses in bends in circular pipes, according to Weisbach's rule, have been calculated for various velocities and curvatures, and tables of them can be found in handbooks on hydraulics. These tables serve as a useful check on the designer; but, in pumps, the distribution of the flow within the pipes is rarely as has been assumed in the calculations. In general, in pipes of circular section, circular bends should have a radius of 5 diameters (according to Weisbach's rule) or 3 diameters (according to experiment). Larger radii are of no advantage, while smaller radii increase the losses. Assuming Weisbach's rule to be correct, the loss due to curvature in the casings of centrifugal pumps of the best designs is comparatively small.

APPENDIX I.

Departure in the Present Paper from Theories Published Previously.

It has been assumed by some writers on centrifugal pumps that the only forces which do useful work on the water in a centrifugal pump are centrifugal forces. If this were true, the maximum lift

of any centrifugal pump could not exceed $\frac{u^2}{2\,g}$; but it is the common experience that many pumps of this type produce higher heads.

In his paper, entitled "The Centrifugal Pump," Mr. Unwin states, as a theoretical fact, verified by experiment, that a current flowing through a channel with an abrupt enlargement of suction suffers a dissipation of head equal to $\frac{v_1^2 - v_2^2}{2\,g}$ feet, where v_1 is the velocity in the smaller channel and v_2 that in the larger; and he develops a part of his theory upon this assumption. The writer differs with this theory, and his experiments do not sustain it.

The flow of water in channels of changing section, and through pipes and orifices, has been studied by many, but there remains much to do in this field. Entry head, apparently, has received more attention than emergence head; and to the lack of specific statement of the facts in this field is due largely the idea that the velocity of discharge from a pump is lost, as far as useful work is concerned—a general and pernicious error.

If the equation, $2\,g\,h = v_1^2 - v_2^2$, were true for an abrupt change of section of the water channel, as represented by the confining walls, a pipe discharging water into the bottom of an infinite basin would produce no head whatever in that basin; while, as a matter of fact, it does produce a head, in many cases almost equal to $\frac{v_1^2 - v_2^2}{2\,g}$, as the writer has found in many cases with large discharge pipes.

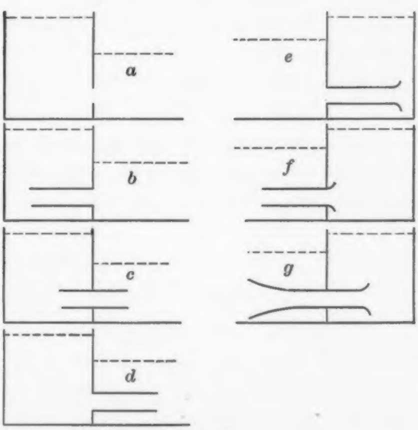


FIG. 12.

The following experiments, illustrated in Fig. 12, were made to determine (qualitatively only) the effects of various arrangements of intake and discharge on a short pipe. The pipe used was $\frac{5}{8}$ in. in diameter and $2\frac{1}{8}$ in. long. The water sup-

ply was constant, and the head taken by the pipe varied. Fig. 12, *a,* shows the arrangement which required the greatest head to pass the given quantity; and each succeeding letter, *b, c* and *d,* designates the arrangement which required the next least head to pass the same quantity. The size of the smallest section was the same in each case; and the same tube was used in each experiment.

In every case the water emerged from the orifice in a well-defined current which was reduced to head if the body of water in which it could expend itself was large enough. In Case *e,* the eddy in the discharge pool apparently contracted the stream very slightly, while the contraction was not noticeable in Case *f.* Case *g* showed an advantage over Case *f,* which became less the greater the length of the discharge reservoir, to allow a free expenditure of the emergence velocity.

From these experiments, the writer is of opinion that some of the tests which, apparently, have shown abrupt losses of head in pipe channels with sudden enlargements in section must have been incomplete; that is, they must have located, only apparently, a large loss at the joint, and that it would be found from more extended observation that the hydraulic grade is somewhat like that indicated in Fig. 13.

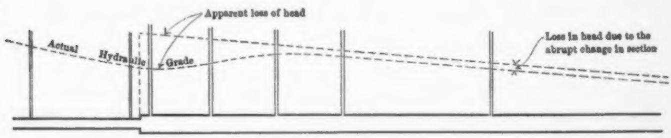


FIG. 13.

The writer has not had leisure to test this particular surmise by direct experiment, or to show how the head is distributed beyond an enlargement in the pipe.

APPENDIX II.

METHODS OF MEASURING DISCHARGE AND HEAD.

On several occasions the writer has examined records of tests in which head has been measured by piezometer tubes. These readings are invariably too high if there are any pulsations of velocity or pressure in the water, such as those produced by the limited number of runner vanes. That these pulsations increase

the losses in the pump has been explained, and that the distortion of flow may result in the production of a lower mean effective head than that produced by an ideal distribution of the flow has likewise been explained. But the tubes give readings higher than the actual effective head, the reason being that the column of water in the piezometer tube does not move in phase with the motion of the column of water in the discharge pipe, nor does it have the same inertia per unit cross-section. In testing a badly designed pump by piezometer readings for head, the pump may be given credit for as much as 25% more head than it is producing in useful form; that is, than the actual mean effective head which causes the quantity of water actually discharged to flow through the pump. In one instance which has come under the writer's observation the head measured by this method, if correct, would have indicated that a pump runner in a given pump with its discharge pipe and suction pipe caused a head and a current of certain value, while another runner in the same casing and pump system produced a greater head yet caused a less current. The difference really arose from the fact that one runner caused greater pulsations in the pressure than the other. In each case the flow in the discharge pipe must have been fairly constant, because the pipe was about 1 000 ft. long and would not respond suddenly to slight pulsations, while the piezometer tubes were short, and the water in them was pulsating and not discharging at all, and, of course, was entirely out of phase with the pulsations in pressure. In another case, that of a very large screw pump, piezometer tubes showed a difference of head between the suction side and the discharge side of the pump which, if correct, would indicate that the pump had an efficiency of more than 100%, while the actual efficiency was about 58 per cent. The quantity discharged and the power taken were known accurately, the pump being driven by an electric motor of known efficiency, with test instruments in the feeder lines. As lag, or phase difference between current and electromotive force in alternating or pulsating electric currents is the result of self-induction, so these effects in these hydraulic currents are the result of the mass or the inertia of the fluid. If the rate of change of pressure and the mass of the moving current were known, the lag could be calculated and a power factor found which could be applied to the readings of any particular tube; but the pulsations are by

no means simple in form, and their amplitude is not known, so that any correction from purely theoretical reasoning is not practicable. The only way to eliminate the errors is to get rid of the immediate effect of the mass of the discharge stream, as by introducing a large air chamber in the path of the water between the pump and the discharge pipe and taking the readings of head in the discharge pipe. The air chamber must be of sufficient size to allow for a complete disappearance of all the rapid pulsations, and the placing of an air chamber in the piezometer tube only will not correct the readings, but will make them more steady and easy to read; in other words, help conceal the fact that the pulsations are serious. Another method of partially neutralizing the error of piezometer readings of this kind, when taken from points where the pulsations in pressure are serious, is to introduce in the path of the piezometer tube a column of water equal in length to the length of the discharge pipe of the pump from the point where the tube is inserted to the point of free discharge. Thus the inertia per unit area of the piezometer column will be equal to the inertia per unit area of the discharge stream, and the two circuits will be approximately in phase. It is far better, however, to take measurements of head by some method which is not affected by pulsations in the discharge pressure or current, if that is possible, as by observing directly the difference in elevation of the surface of a discharge basin and the surface of a suction basin, and, where long pipes intervene, determining the heads consumed in them by independent measurements with currents which are not derived from a source of fluctuating pressure. These remarks do not apply to piezometer measurements where the currents are steady, or where the pressures oscillate so slowly as not to produce any appreciable lag.

APPENDIX III.

In the body of this paper the writer has endeavored to point out the importance of unequal distribution of flow between the vanes, and to indicate certain methods of keeping the losses due to this cause as small as possible. As centrifugal pumps are actually built, the curvature of the vanes and the proportions of the waterways rarely conform even approximately to the lines indicated as desirable in this paper, and a large correction of the formulas is

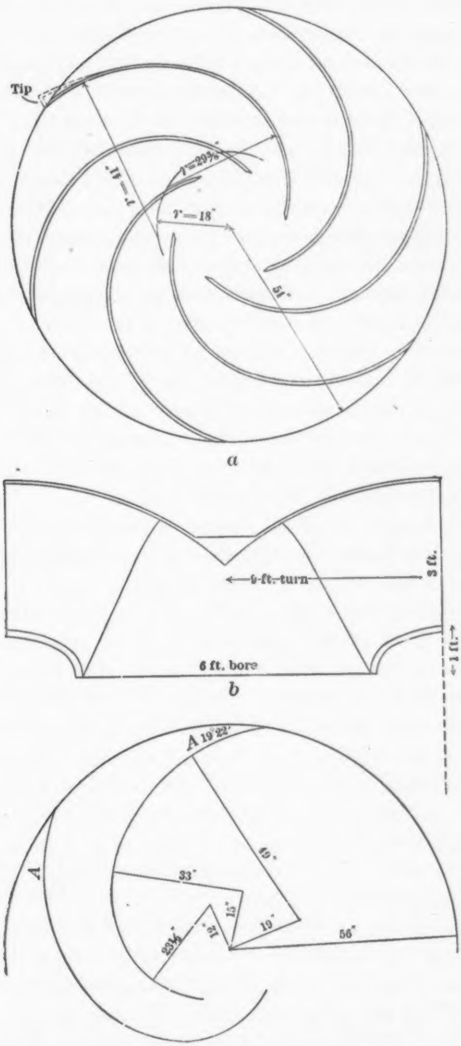


FIG. 14.

needed in order to predict the discharge accurately. From a consideration of the various designs of pumps actually on the market and from the somewhat meager literature of the subject, in which it is so often stated that the actual form of the vanes is of no importance, it appears that this part of the design has been purely empirical. The writer has compared the test data of a number of very large pumps with the calculations of the theoretical performance of the same pumps if they had been possessed of ideal vanes. The comparisons satisfy him of the correctness of the principles of design given in the paper and furnish many special data regarding the actual losses in particular designs, and corrections necessary to the ideal formulas in order to predict the head.

It is not the present purpose to give many of these data in detail; but, to indicate the importance of the form of the vanes, and the large effect, upon the discharge of any pump, which may be produced by comparatively slight changes in the form of the vanes, the following presentation and discussion of the test data of two large pumps have been introduced.

Fig. 14, *a* and *b*, gives the outline of the design of a centrifugal pump installed in the New Orleans Drainage System, and intended to discharge 250 cu. ft. of water against a head of 10 ft., plus certain losses in the suction and discharge pipes, when driven at a constant speed of 62.5 rev. per min. by a synchronous electric motor. There are six vanes to the runner. The pump as designed threw less than the required quantity. To make it throw more, the runners were tipped, as shown by the dotted line in the figure. The ends of the original vanes were not removed. Thus the runner did not approach to an ideal shape, and its displacement, especially at r_2, was extremely great. The curvature of the vanes, and the acceleration producing v, was not uniform at various points on the edge of the vane. The casing of this pump is of the usual type, enlarging on a spiral curve.

At a later date, another pump, of the same nominal capacity, was installed, for the purpose of increasing the output of the station. This second pump differed from the first only in the runner and the arrangement of the suction passages. The two casings were made from the same pattern, and the discharge pipes were exactly alike. The runner of this second pump is shown in outline in Fig. 14, *c*.

These pumps were tested for discharge, head and efficiency.

The power was measured by electrical instruments placed in the feeder lines. The efficiency of the motors was known, and, in consequence, the power delivered to the pump-shaft could be calculated readily. As the power consumed did not vary much when the head varied, there was little error in assuming that the efficiency of the synchronous motors, when there was no lag in the current, was constant, and this was assumed. The error from such an assumption could not exceed 0.5%, if it ever reached that amount. The water was measured in a flume on the discharge side of the pumping station, a considerable distance from the station, so as to secure practically uniform and quiet flow; but the distance was

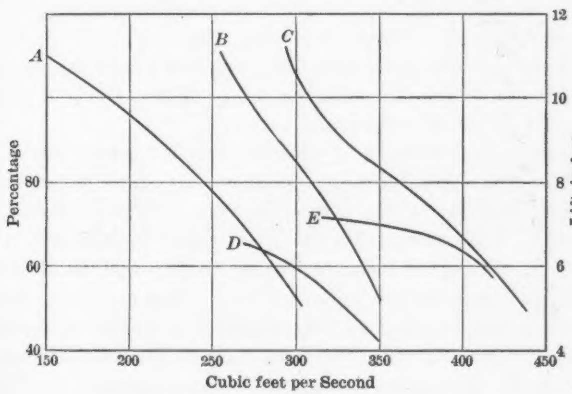


FIG. 15.

not so great as to introduce any considerable error from the reservoir effect of canal between the pumps and the flume. The canal was allowed to fill up with water on the suction side, and was then pumped down, and the capacity of the canal on the suction side was so great that it took several hours to pump it out, so that the change was very gradual. The difference in level between the water in the suction basin and the discharge basin was measured by the difference between the height of the water on fixed gauges which were placed in quiet water communicating freely with the basins. The writer considers the method peculiarly accurate for such tests. The errors, if there were any considerable ones, must have arisen from lack of skill of the operators in taking readings

of the instruments, but, as there were several readings taken at each head, the errors from this cause could not have been great. The writer was not present at these particular tests, but he was present at similar ones conducted at other stations.

Fig. 15 shows the relation between discharge and head produced by the pumps; also the relation between discharge and efficiency. The curve, *A*, gives the discharge and head of the first pump before the vanes were tipped. This curve is not as accurate as the others, as the speed of the engines which drove the generators from which the three-phase electric current was taken was not quite steady, and as the test was not continued after it was demonstrated that the discharge at 10 ft. head was less than required by the contract. But it serves to show approximately, in connection with the curve, *B*, the effect of tipping the vanes. The curve, *B*, shows the performance of the pump after the vanes had been tipped, as indicated in the outline drawing, Fig. 14, *a*. Curve *C* shows the performance of the second pump.

From these curves, it is apparent that differences which look small on the outline drawings produce very great differences in the performances of the pumps, in such designs as these. The efficiency of the pump with the vanes tipped is indicated by the curve, *D*, and that of the second pump by the curve, *E*. It will be noted that the tests did not extend over a sufficiently great range to demonstrate at what head the efficiency is maximum, especially on the pump with the smaller discharge. The curves, however, indicate that the higher efficiency of the second pump is very largely due to its larger capacity, and that the efficiency of the other would have been materially higher if the head pumped against had been higher than that at which any accurate readings were taken. The tests, from which these curves, *A, B* and *C*, were plotted, were made with the same instruments, and were conducted on consecutive days.

From these curves, alone, the correspondence between the behavior of these actual pumps and ideal pumps with runners of the same form cannot be shown. It is necessary to determine the values of w_1 or w_2 which correspond to the discharges observed, and to plot the curves with reference to these values, in connection with the ideal curves, in order that they may be compared. Before doing this, however, some attention should be paid to a determination of the total useful head developed by the pump, and to a deter-

mination of the losses which can be accounted for outside of the pump proper.

The angle, β, can be determined for the actual vanes at any point, as the radii of curvature are all given. It will be seen in the figures that the vanes extend nearer to the shaft on one side of the runner than on the other, but that their curvature is the same on a given radius. We may take r as 24 in. as a fair average of the radius at entrance, in a preliminary examination of the design. Fig. 16 shows graphically the values of v at various radii, for

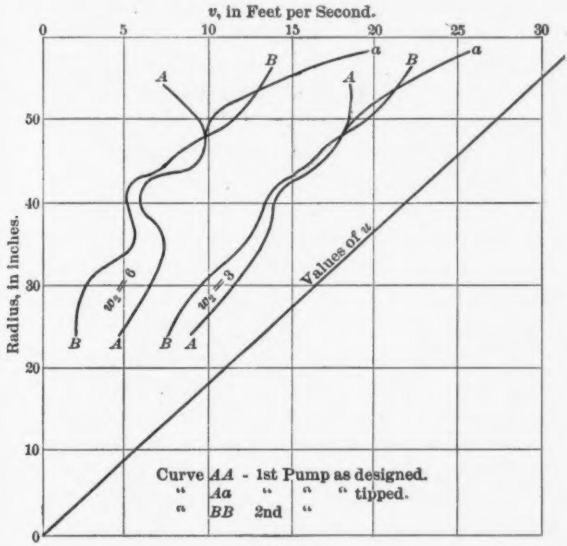


FIG. 16.

various values of w_2, for the second pump, and for the first pump if the pump were ideal with vanes according to the original design, and if the vanes were ideal according to the modified design, as amended by the tipping of the vanes. It will be seen from the curves in this figure that v does not vary uniformly from a fixed minimum to a maximum at any value of w_2, but that the change in v takes place in a series of pulsations, due to the uneven changes in the curvature of the vanes. The section at the intake of the pump is 6 ft. in diameter, which makes an area of 28.27 sq. ft.

Assuming that the distribution of the flow at entrance is uniform in this cross-section, at 250 cu. ft. discharge, the velocity there is 8.85 ft. per sec. The passages leading to this opening are not ideal, and the following heads must be produced to overcome the losses in the suction passages: An entry head of about 0.2 ft. at the gate on the suction side, where the pipe is 8 ft. in diameter; a friction head in the suction pipe of not more than 0.1 ft.; a loss of not more than 0.25 ft. in an enlarged pit between the 8-ft. suction pipe and the pump suction.

On the discharge side the pump is 8 ft. in diameter, and the losses are approximately as follows: Friction in the pipe 0.1 ft.; loss at the exit of the pipe into the discharge basin, which is a square joint without any provision for saving this loss, not to exceed 0.2 ft. The total sum of all these losses, which are external to the runner and casing, is 0.85 ft. head. This must be supplied by the pump, in addition to the head pumped against and the losses in the runner and the casing, and to the mechanical friction of the bearings. The expedient of avoiding the pit between the suction pipe and the suction of the pump was adopted in the installation of the second pump, and the loss there reduced to about 0.15 ft. in the bend, while all the other arrangements were the same as in the other installation. This was the most advisable change, and the one most readily made; and a certain part of the increased efficiency of the pump unit, as shown in Fig. 15, was due to this change. The other expedient which could have been adopted to reduce the loss outside of the pump was the enlargement of the pump passages, and that would have required a very much more expensive pump, a motor of slower speed, a larger building, and would have increased the cost greatly.

Within the pump itself there is a loss of head which is not due to the shape of the vanes, and which could not have been avoided by forming them ideally. This is the loss due to the change in the direction of the flow from a line parallel with the axis to a plane radial to the axis, within the pump itself. Among the accepted special applications of Weisbach's rule, there is no accurate formula for calculating this loss, though such may be obtained for specially formed passages, but from a comparison with similar losses in ordinary bends in pipes it appears that this loss could hardly be greater than 0.25 ft. in this case. The velocity of the

water does not change much while making this curve, but only a small component of the diverted velocity appears as radial flow, the remainder being converted into v at entrance.

This makes a total head of 1.10 ft. in one pump and 1 ft. in the other to be overcome, in addition to the losses due to friction within the pump and the unequal distribution of the flow between the vanes owing to there being a limited number of them, and to

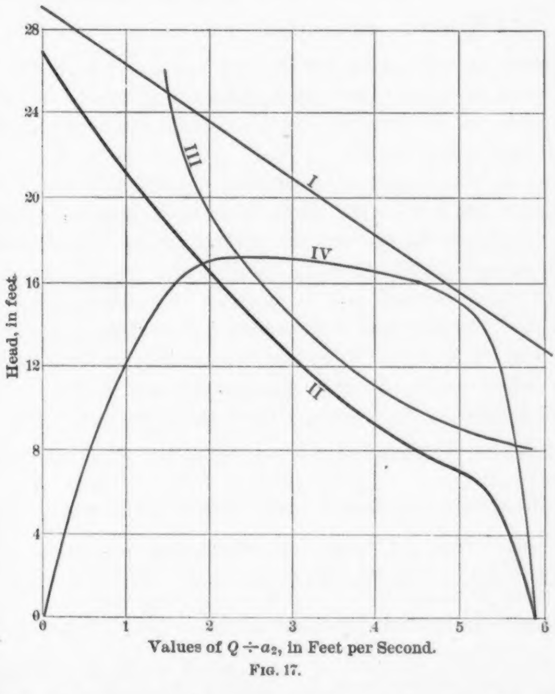


FIG. 17.

the loss of flow due to leakage, and the loss of power due to mechanical friction.

If we are to study the losses due to the runners, only, we must consider that the pump produced a total head of 11.1 ft. that was useful, instead of 10 ft. only, which was the useful head produced by the pump and waterways combined. We must also eliminate from our values of power the losses due to friction of the bearings.

These friction-bearing losses may fairly be taken as not more than 3% of the total input, and, as the efficiency of the pump at about 250 ft. discharge was 65%, we may consider that the hydraulic efficiency was about 68 per cent. The leakage, from an approximate calculation of the area of the joint and the pressure of the water there (the total pressure of the pump) was less than 0.5%, and it is a fair assumption, in view of all these facts, that the hydraulic efficiency of the runner and casing at normal discharge was very close to $\frac{11.1}{10} \times 68.5 = 76$ per cent. This shows a loss of 24% in the runner and the casing, for the first pump, at 250 ft. discharge. The second pump, at a little greater discharge, shows a corresponding efficiency of about 80.8%, and this difference is ascribable chiefly to the form of the vanes.

Having thus distinguished between the hydraulic efficiency of the station and that of the runner and casing proper, we are prepared to compare the performance of these pumps with ideal pumps of the same form of vanes, to examine the peculiarities of the form of vanes adopted, and to determine the effect of distortion of the flow upon the total head produced at any discharge.

In Fig. 17, Curve I shows the relation between head and discharge which would obtain in the second pump if there were an infinite number of ideal vanes shaped as in the outline drawing. Curve II shows the actual relation between h_e and $\frac{Q}{a_2}$, as determined by the test. Curve III shows the relation between h_c and $\frac{Q}{a_2}$, in the actual pump. The values of h_c are obtained by dividing h_e by the hydraulic efficiency obtained from the test. Curve IV shows the relation between hydraulic efficiency and $\frac{Q}{a_2}$. The distances from Curve I to Curve III show the heads which would have been produced if there had been no distortion of flow, but which were not produced, on account of the distortion. The distances from Curve II to Curve III show the values of h_d for all values of $\frac{Q}{a_2}$. Parts of these curves were plotted from the data of actual tests; but the extremes of the curves are hypothetical.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 59.

PUMPING MACHINERY.

MUNICIPAL WATER-WORKS PUMPING ENGINES.

BY IRVING H. REYNOLDS, M. AM. SOC. M. E.

While there have been no special innovations in American pumping-engine practice during the past decade, there has been a marked tendency toward accepting certain designs as a standard, and the high and steadily increasing efficiencies attained may warrant a brief review of this branch of steam engineering.

It is proposed to devote this paper entirely to municipal water-works engines, as it is with the development of this class of machinery that the writer has been particularly identified.

Prior to 1893 no pumping engine had attained a duty of 150 000 000 ft-lb. per 1 000 lb. of steam (equivalent to 12 lb. of steam per i. h. p. hr.), but in that year a triple-expansion engine of the writer's design in the Milwaukee Water-Works gave a duty of 154 048 700 ft-lb. with a steam consumption of 11.68 lb. per i. h. p. or 217.6 B. t. u. per i. h. p. per min.*

* All figures in this paper, unless otherwise stated, are based on saturated steam, the coal duties being per 100 lb. (not per hundredweight), and the capacities are in U. S. gallons of 8.34 lb. or 231 cu. in.

The test was conducted by Professor R. C. Carpenter, of Cornell University, and was the subject of a paper by the late R. H. Thurston, M. Am. Soc. C. E.,* and, while the figures do not now appear at all remarkable, yet they showed so great an advance over previous practice, as to cause much discussion and some question as to their accuracy.

This engine was supplied with steam at less pressure (125 lb.) than was considered essential for the economical operation of a triple-expansion engine and, in addition, ran at the comparatively slow speed of 200 ft. per min.

Tests of six similar engines, made soon after by the same builder (The Edward P. Allis Company), five at Chicago and one at Detroit, gave substantially the same results and confirmed the Milwaukee figures.

The first engine to exceed the Milwaukee duty was the Boston high-service (Chestnut Hill) engine designed by E. D. Leavitt, M. Am. Soc. C. E., and tested in 1895, and from this time progress has been steadily upward as shown by Table 1, which covers the more important engines tested during the past ten years.

It will be noted that these engines, with two exceptions, are of the vertical triple-expansion type and that, as a rule, the steam pressures are below 150 lb., and the piston speeds are generally about 200 ft. per min.

The vertical compound engine (No. 2 in Table 1) is notable as holding the record for a compound engine, having shown, on a six-day test, a duty of 148 655 000 ft-lb., with a steam consumption of 12.15 lb. per i. h. p. hr., and having given an average annual duty of about 120 000 000 ft-lb. per 100 lb. of coal, a performance equaling that of many triple-expansion plants.†

The Nordberg quadruple-expansion engine (No. 7 in Table 1) is notable for having established the record for low heat consumption, the figures being 162 132 500 ft-lb. per 1 000 000 B. t. u., or 186 B. t. u. per i. h. p. per min., the thermal efficiency being about 22.8 per cent.

These remarkable results were obtained principally by the use of feed-water heaters placed in the exhaust pipe, 3d, 2d and 1st receivers

* *Transactions*, Am. Soc. Mech. Engrs., Vol. XV, 1894.

† The New Bedford engines (No. 17, Table 1) are reported to give an average annual duty exceeding 130 000 000 on coal.

TABLE 1.—PERFORMANCES OF PUMPING ENGINES, 1893-1903.

	Builder or designer.	Date of test.	Location of engine.	Type of engine.	Capacity, in gallons per 24-hr.	Piston speed, in feet.	HEAD. Feet.	HEAD. Pounds.	Steam pressure, in pounds.	Indicated horse-power.	Percentage of mechanical efficiency.	Steam, i. h. p., hour.	B. t. u., i. h. p., minute.	Duty, in foot-pounds per 1 000 000 B. t. u.	Duty, in foot-pounds per 1 000 pounds steam.	Percentage of thermal efficiency.
1	Edward P. Allis Co...	1893	Milwaukee, Wis.	Vertical Triple.	18 000 000	203	162.6	70.4	121	574	91	11.68	217.6	137 656 000	154 048 700	19.40
2	E. D. Leavitt..........	1894	Louisville, Ky.	" Compound.	16 000 000	371	193.3	83.7	137	643	93	12.15	222.5	137 565 000	148 655 000	19.07
3	" "	1895	Boston, Mass.	" Triple.	20 000 000	607	137.2	59.4	176	576	89.5	*11.22	*204.3	*144 500 000	*157 843 000	20.76
4	Lake Erie Eng. Wks..	1897	Buffalo, N. Y.	" "	30 000 000	208	199	86	167	1 186	95	12.39	231.2	135 000 000	152 000 000	18.35
5	Snow St. Pump Co...	1898	Indianapolis, Ind.	" "	20 000 000	215	205	89	156	776	95.4	11.26	207.6	150 100 000	167 800 000	20.45
6	Edward P. Allis Co...	1899	Cleveland, Ohio.	" "	20 000 000	200	202	87.5	149	770	93.7	11.45	213	145 220 000	161 990 000	19.9
7	Nordberg Mfg. Co....	1899	Wildwood, Pa.	Quadruple Expansion.	6 000 000	256	604	262	200	712	93	12.26	186	162 132 500	149 500 000	22.8
8	Edward P. Allis Co...	1899	St. Louis, Mo., No. 7.	Vertical Triple.	10 000 000	175	294	127.5	136	549	94.3	11.63	216.8	143 404 000	160 455 000	18.44
9	" " " ...	1899	" " No. 8.	" "	10 000 000	175	294	127.5	137	545	94.9	11.63	216.5	144 365 000	161 530 000	18.59
10	" " " ...	1900	Hackensack, N. J.	" "	12 000 000	211	267	115	173	603	94	11.05	211.9	146 403 400	168 532 800	20.00
11	" " " ...	1900	St. Louis, Mo., No. 9.	" "	15 000 000	198	293	127	127	813	96	10.78	204.4	155 237 450	176 419 600	20.78
12	" " " ...	1900	" " No.10.	" "	15 000 000	197	292	126	126	802	96.8	10.68	202	158 077 320	179 454 250	21.00
13	" " " ...	1900	Boston, Mass.	" "	30 000 000	195	140	61	185	748	93.3	10.33	196	163 925 300	178 497 000	21.63
14	E. D. Leavitt..........	1901	Cambridge, Mass.	" "	21 000 000	496	190	82	178	780	93.4	12.17	221	135 816 000	146 173 000	19.43
15	Holly Mfg. Co.........	1901	Boston, Mass.	" "	35 000 000	300	45	19.5	151	323	88	11.10	210	141 532 000	157 349 000	20.50
16	" "	1901	" (Spot Pond)	" "	20 000 000	248	125	54	150	464	96.5	11.01	203.4	156 592 000	173 620 000	20.85
17	E. D. Leavitt..........	1903	New Bedford, Mass.	Two Vertical Compound.	10 000 000	480	185	80	181	342	95	13.46	223.9	150 010 000	140 000 000	18.95
18	Edward P. Allis Co...	1903	St. Louis, Mo., No.11.	Vertical Triple.	15 000 000	197	293	126.9	138	800	97.2	10.84	204.8	155 800 000	177 300 000	20.72
19	" " " ...	1903	" " No.12.	" "	15 000 000	197	293	126.8	135	796	97.7	10.88	205.2	156 900 000	177 200 000	20.67
20	Allis-Chalmers Co.....	1904	" " No. 1.	" "	20 000 000	198	240	104	...	....	....	.....	.....	....	176 866 000	.....

*Exclusive of auxiliaries.

taking the feed water from the condenser and passing it through the heaters, in the order named, on its way to the boilers. This arrangement caused considerable condensation in the receivers (about 15% of the total steam used by the engine), and the gain in economy was due to the utilization of the latent heat in this 15% condensed.

Considering that this engine was of the quadruple type and supplied with steam at 200 lb., it would seem, when compared with the performances of some of the triple-expansion engines, that the economy might have been attained without the use of the special heaters.

While exceedingly interesting from a theoretical standpoint, the system apparently involved so much complication as to bar its general introduction.

As far as is known the record for general efficiency is now (July, 1904) held by the 30 000 000-gal. Allis engine at the Chestnut Hill Station of the Metropolitan Water-Works, Boston. This engine on the official test with steam at 185 lb. and a piston speed of 195 ft., showed a duty of 178 497 000 ft-lb. per 1 000 lb. of steam, 163 925 300 per 1 000 000 B. t. u., 196 B. t. u. per i. h. p. per min., 10.335 lb. of steam per i. h. p. hr., 1.06 lb. of coal per i. h. p. hr., and a thermal efficiency of 21.63% (22.58% including economizer).

The three (Holly) low-service engines at Chestnut Hill, Boston (No. 15 in Table 1), are notable for the very high duty obtained under the low head (45 ft.) against which they operate.

That the obtaining of high economy is not a matter of chance is indicated by the practically identical performance of the three Holly engines already noted and the Spot Pond engine of the same builder, the steam consumption being 11.10 and 11.01 lb. per i. h. p., respectively; and further examples are the five St. Louis engines (Nos. 11, 12, 18, 19 and 20 in Table 1), which though tested some three years apart, gave substantially the same results, *i. e.*, 10.63 to 10.78 lb. of steam per i. h. p. per hr.

Direct-Acting Engines.

For capacities up to 3 000 000 gal. the direct-acting duplex pump is commonly used, and not infrequently, where fuel is cheap, this type of pump, either as a compound or triple, is used for capacities of 5 000 000 gal. or upward.

The duties usually guaranteed per 1 000 lb. of dry steam are about 60 000 000 for compound condensing, 90 000 000 for triple-expansion condensing, and 110 000 000 for compounds with high-duty attachments, and 130 000 000 for triple-expansion machines with high-duty attachments.

Many attempts have been made to secure the economy of the crank and fly-wheel engine while retaining the cheapness and simplicity of the direct-acting pump, but these efforts beginning with William Wright on the Brooklyn engines many years ago, and including the designs of Worthington, Heisler, D'Auria and others, have not been successful to any great extent, excepting in the case of the Worthington compensating device, which has been fitted to many important engines (notably those at Brooklyn, St. Louis and Chicago), and has given relatively high economy; but, in recent years, owing to the consolidation with other interests, this type of engine has not been offered to any extent, and, that water-works engineers do not consider it equal to the crank and fly-wheel type, is shown by the fact that nearly all specifications for large engines now call for the latter design.

For capacities from 3 000 000 to 5 000 000 gal., when high duty is desired, the compound crank and fly-wheel engine is very generally used, and, where the situation is such that a horizontal engine is preferable, this type, up to 10 000 000 or 12 000 000 gal. capacity, is occasionally built, though there is a growing tendency to use vertical engines for even very moderate capacities.

The simplest form of horizontal crank and fly-wheel pump consists of a cross-compound engine with a pair of double-acting pumps placed tandem to the steam cylinders, and while this type is in common use in Europe and possesses many desirable points in the way of simplicity and accessibility, it has not been extensively used in American water-works plants, partly on account of the rather excessive space occupied but, principally, because certain other and more compact types have been more vigorously exploited.

The "Holly-Gaskill," a horizontal engine of the "Woolf" compound type, was the first high-duty crank and fly-wheel engine regularly built as a standard machine, and while giving relatively high economy, it has some constructional disadvantages, and is now, to an increasing extent, being succeeded by the more direct types,

such as the "Snow," and for the larger capacities, by vertical triple-expansion engines.

In the "Snow" engine the pumps are placed *vis-a-vis* to the steam cylinders, the steam pistons being rigidly connected to the pump plungers by tie-rods which straddle the crank shaft as in the case with vertical triple-expansion engines. This type of engine, while occupying more space than the "Gaskill," has the important advantage of direct transmission of power from the steam pistons to the pump plungers and greater accessibility of the parts and, for the medium and larger sizes, it represents, in the writer's opinion, the best type of horizontal engine.

The duties usually guaranteed for horizontal compound crank and fly-wheel engines range from 110 000 000 to 130 000 000 ft-lb. per 1 000 lb. of steam.

The horizontal crank and fly-wheel engine is built occasionally as a triple-expansion machine, although there is ordinarily little to recommend it. It occupies much more space, gives but little better flow of water than the compound, and does not give a sufficiently higher economy to justify its largely increased cost, the triple-expansion system being best adapted to the vertical crank and fly-wheel and the horizontal direct-acting types.

Vertical Engines.

Practically all of the larger vertical engines built during the past few years have been of the triple-expansion type, and these, with the exception of the machines designed by Mr. Leavitt, follow the general design of the original triple-expansion engine built for the Milwaukee Water-Works in 1886 by the Edward P. Allis Company.

This type of engine, having been accepted as the standard pumping engine of to-day, is so well known that even the following brief description may hardly be necessary.

There are three cylinders, high, intermediate and low pressure, arranged in the order named and mounted on the tops of the main frames which are, in the smaller engines, usually of a modified "marine" type, and, in the larger machines, of the double "*A*" type.

The shaft which is carried in the bed-plates below the main frames has three cranks set at angles of 120°, and on this shaft two fly wheels are mounted.

The pumps which are usually of the single-acting type, are placed immediately below the main bed-plates and the plungers connected to the steam cross-heads by "distance" rods passing on either side of the shaft and behind the cranks, and, from the cross-heads, connecting rods extend to the crank pins in the usual manner. This construction gives a direct and rigid connection between the steam pistons and pump plungers, and the plungers being weighted so that equal power is required on the up-and-down strokes, very little work (principally that transmitted to and from the wheels) is transmitted through the shaft.

Owing to the use of 120° cranks the flow of water is so nearly uniform as to leave nothing further to be desired in this direction.

It has been argued that with the low steam pressure often used, a compound engine would give, practically, the same economy as the triple and at much less first cost. While this is to some extent true the fact is overlooked that economy is not the sole reason for the adoption of the triple, but that the general excellence of the "triplex pump" for handling water and the adaptability and flexibility of the machine, as a whole, are the factors which are responsible for its wide popularity.

Having determined on three single-acting pumps as the best and simplest form, it is essential, in order to drive them direct, to have three steam cylinders and thus there is obtained the triple expansion engine, practically without increased cost and with a steam economy of from 10 to 20% higher than that of a compound engine working under similar conditions.

In the earlier vertical engines the bed-plates usually rested on masonry piers with the pumps placed between them, but later the cost of the foundation was reduced by omitting one of the piers and utilizing the pump air-chambers to support one end of the engine bed-plates, this construction being known as the semi-self-contained type. Other modifications have been made by the construction of completely self-contained machines and by the omission of masonry piers, the engine superstructure being supported on framing carried down to base plates below the pumps, and, in another design, the pumps are built with double chambers and support the engine bed-plates without the use of any framework whatever.

In most locations the semi-self-contained machine has every

practical advantage of the completely self-contained type and at less first cost, and when the self-contained engine is required, the design in which the pumps form the support for the engine proper is ordinarily to be preferred to that involving the use of framing, as it gives greater accessibility and at less cost.

The argument that the use of lower frames facilitates the removal of broken pumps is not complimentary to the builders, and, in practice, is a very expensive provision against a comparatively remote possibility.

The adoption of the triple-expansion pumping engine is proceeding very rapidly, particularly, in the larger cities: Boston having six in the Water-Works and eleven in the Sewerage Department; New York, four; Philadelphia, six or eight in use and as many more under construction; Cleveland, five; Detroit, three; Chicago, twelve, with others building; Milwaukee, four, and one under construction; Cincinnati, ten under construction; Louisville, two building, besides many other cities which have one or more engines in operation or building.

The most complete equipment of modern pumping engines is, however, in the St. Louis Water-Works, there being at the Chain of Rocks Low-Service Station, two Worthington engines of 20 000 000 gal. capacity each, and four Allis engines of 30 000 000 gal. each, all being of the vertical compound high-duty self-contained type; while at the Baden Station there are six, and at Bissells Point, three vertical triple-expansion engines, ranging in capacity from 10 000 000 to 20 000 000 gal., all but two of the engines being of the self-contained type and all having records for economy, which have never been equaled under similar conditions.

The duties usually guaranteed for triple-expansion engines vary from 140 000 000 for small engines with moderate steam pressures to 160 000 000 (and occasionally higher) for large engines with steam pressures from 150 to 175 lb.

Enough has been said to indicate the position of the triple-expansion engine and the following as to details may be of interest.

Valve Gear.

The Corliss valve gear is in practically universal use on all American high-duty pumping engines of recent construction, the

exceptions being, principally, the engines designed by Mr. Leavitt, which are fitted with cam-operated gridiron valves.

On the larger vertical engines it is now customary to use poppet exhaust valves in the low-pressure cylinder, and on the very largest machines poppet valves are used for both the steam and exhaust of the low-pressure cylinder as well as the exhaust of the intermediate cylinder. These valves are of the "single-seat" poppet type, set directly in the cylinder heads, the exhaust valves opening directly into the cylinder, and all of the valves, when seated, being flush with the cylinder heads.

The Corliss valves are in vertical engines also usually placed in the cylinder heads, this arrangement reducing the clearance in the case of Corliss valves to 1 or $1\frac{1}{2}\%$, and in low-pressure cylinders where poppet valves are used, the clearance is brought down as low as $\frac{1}{2}$ of 1 per cent. The use of poppet valves not only reduces the clearance, but insures absolute tightness.

Poppet valves have not come into use on the high-pressure cylinders, as superheated steam has not, as yet, been introduced in pumping-engine practice, but, even if it were, the Corliss valve is entirely capable of handling a moderate degree of superheat satisfactorily.

It is customary to fit all crank and fly-wheel engines with governors of the ordinary fly-ball type, these governors being sometimes arranged to control the engine at all speeds and, in other cases, only to act as a safety device when the maximum speed desired is attained. Comparatively few engines are fitted with pressure regulators as it has been found that the water pressure acting against the pump plungers is in itself the best speed regulator, especially where the engines are operated with fixed cut-offs, thus maintaining a constant load in the steam cylinders.

JACKETING.

It is customary to steam jacket all cylinders but in the case of engines with valves in the head, only the barrels are jacketed. It is a very general practice to jacket the low-pressure cylinders with steam at reduced pressure, and on triple-expansion engines, particularly, this pressure is carried only a few pounds above the initial of the steam entering the cylinder.

The receivers between cylinders are usually fitted with reheating coils or tubes operating in connection with the cylinder jackets.

PUMPS.

On horizontal engines the pumps are almost universally of the double-acting type, and, where the pressure is of any considerable amount, commonly have outside packed plungers.

Vertical pumping engines, especially of the triple-expansion type, are fitted with single-acting outside packed plungers, and vertical compound engines for reservoir work are also best fitted with single-acting pumps, while for direct service they may have either differential or double-acting plungers.

PUMP VALVES.

American designers have never adopted the mechanically controlled valve nor the multi-ported ring valve common in European practice, but they have quite generally accepted rubber valves as satisfactorily fulfilling all the requirements of ordinary practice.

These valves are simple rubber discs of small diameter (usually not over 4 in.), and it is quite customary to mount the valves in groups on hexagonal or octagonal turrets, or "cages," this arrangement enabling the designer to obtain a large amount of valve area in proportion to the diameter of the pump-chamber, and the use of "cages" is also a matter of considerable convenience in operation, as they are held in place usually by a single bolt, and can be removed readily for repair.

Large valve area is provided, usually of such amount as to give a flow of about 3½ ft. per sec. through the valve openings, and this, together with the low lift of the valves, secures quiet operation of the pumps. These valves are exceedingly durable when properly designed and where the water is fairly free from coarse sand, etc., many of them being in continuous service for more than ten years and seating some 125 000 000 times.

AUXILIARIES.

Both jet and surface condensers are used, dependent on local conditions, and while the surface condenser is being used to an

increasing extent, in many cases the water of condensation is thrown away on account of the oil it contains, and, in many others, is so cold that it has no value for boiler feeding and could as well be rejected.

In general, the use of surface condensers is not to be recommended except where there is a scarcity of water, or where the water contains such impurities as to render it unfit for use in the boilers, in which case the water of condensation, when properly freed from oil, is valuable for boiler feeding.

The air pump, feed pumps, and, not infrequently, the compressor for charging the air-chambers, are driven directly from the main engine, and there are many pumping stations in which the only steam used is that which enters the high-pressure cylinders and steam jackets of the main engine, thus maintaining the economy of the station at that of the main engine.

Independent auxiliaries are notoriously wasteful, and in some pumping plants having first-class main engines, the auxiliaries reduce the total economy by about 10 per cent. In one case the independent air pump is reported to use 158 lb. of steam per i. h. p. per hr., and the independent boiler feed pump, 487 lb. per i. h. p., while the steam consumption of the main engine is only about 12 lb. per i. h. p.

Speed.

American water-works managers have been slow to accept higher speed pumps and, perhaps, justifiably so, for while the former speeds of 120 to 150 ft. were unnecessarily low, it is very doubtful whether speeds higher than the 200 to 250 ft. now recognized as good practice, offer any advantage to the purchaser.

Positively controlled pump valves have usually been associated with the idea of high speed, but this type of pump has made no headway in the United States, there being but one engine of this class now in municipal water-works service, though a few are under construction.

It has been generally considered that high piston speed was essential to high steam economy, and not a few pumping engines have been designed with the steam pistons of longer stroke than the pump plungers, but the writer's experience has not shown that there

is any appreciable gain in steam economy in pumping engines due to the use of higher speeds.

An examination of Table 1, previously given, will show that practically all of the highest duties have been reached by engines operating at a speed of about 200 ft. per min. The highest speed is that of Engine No. 3 which ran at 607 ft. per min., and gave a steam economy (exclusive of auxiliaries) of 11.22 lb. per i. h. p. per hr., while Engine No. 13, with steam at but slightly higher pressure and a piston speed of only 195 ft. per min., was about 10% more economical, and Engines Nos. 14 and 17, while operated at speeds of 496 and 480 ft., respectively, are distinctly inferior in economy to many of the other engines given in Table 1, operating at slower speeds and with lower steam pressures.

It is not claimed, however, that the steam economy of a high-speed engine of similar design is inferior to that of the slow-speed machine, but, rather, that despite the theoretical advantages of high speed, the slow-speed engine, on account of its smaller clearances due to reduced ports, etc., gives fully as high economy as can be attained with the high-speed machine.

Under high heads the high-speed pump has some advantage in first cost, but as few American cities pump their water against a head greater than 200 ft., this factor seldom appears.

While it is true that the higher speed somewhat reduces the size, and to a lesser extent the cost, of the engine portion of the machine, yet, as far as the pumps are concerned, the cost of the water end is, if anything, increased, for as the time allowed for the seating of the valves is less, more area must be provided, and to avoid friction losses all pipes and passages must be maintained fully as large as on slow-speed pumps.

As the wear on the valves and on the engine in general is practically proportional to the number of reversals per minute, it follows that the renewals and repairs are greater on the high-speed machine, and in view of the fact that the economy remains the same the question may well be asked: What is to be gained by high speed?

Steam Pressure.

Steam pressures in American water-works have, as a rule, been low, due principally to the fact that new engines were being added to old plants where low-pressure boilers were already in use.

In the newer plants 150 lb. pressure seems to be recognized as a standard, but is occasionally increased to 160 lb. or more.

Owing to the comparatively slight gain in economy due to pressures above 150 lb., it does not seem probable that there will be any considerable movement toward much higher pressures, but that more is to be expected from superheating the steam.

SUPERHEATED STEAM.

So far as the writer is aware, superheated steam has not been used on any important crank and fly-wheel pumping engines, but a number of plants are now under construction where a moderate degree of superheat will be used, and the results will be awaited with interest.

A number of Worthington "high-duty" triple-expansion engines in the Chicago Water-Works have been tested with superheated steam and some remarkable figures obtained as will be seen by Table 2.

As will be seen the superheat varies from 63° to 154° fahr., the steam consumption from 10 to 10.90 lb., and the coal from 1.18 to 1.52 lb. per i. h. p. per hr.

Test E 1 200 (third column) shows the best results, both as to steam and coal consumption though the superheat is only 87° fahr., and it would appear from the steady decrease in boiler efficiency with the increase in superheat, that in this case, at least, there was but little actual gain in commercial economy due to superheating. While the figures are interesting, and, when the type of engine is considered, remarkable, there are such inconsistencies between the various tests and between the important figures of individual tests as to seriously impair their value to engineers.

While it is to be regretted that these figures are not more definite, it would appear from unofficial figures obtained during the regular operation of these engines that the duty on coal runs about 76 000 000 without superheaters and 84 000 000 with superheaters, indicating a gain of about 10% from the superheat.

DUTY.

It has been customary usually to express the duty of pumping engines in terms of saturated steam consumption, which is obviously

TABLE 2.—TESTS OF WORTHINGTON HIGH-DUTY PUMPING ENGINES AT CENTRAL PARK PUMPING STATION, CHICAGO, 1902–03, WITH SUPERHEATED STEAM.

1	Test number	E 1 201	E 1 202	E 1 200	E 1 203	E 1 204	E 1 205
2	Engine number	?	?	?	No. 1	No. 2.	No. 3.
3	Date of test	Nov. 16 & 17, '03	Nov. 12 & 13, '03	Nov. 9 & 10, 1903	Sept. 3 & 4, 1902.	Sept. 8 & 9, 1902.	Aug. 27 & 28, 1902
4	Steam pressure, in pounds	141	142	147	147	145	144
5	Superheat, in degrees fahr.	63.4	71.2	87.2	126.7	142.8	154
6	Vacuum, in inches	26.87	26.73	27	26.7	26.8	27
7	Head on pumps, in feet	152.73	152	153.25	153.8	153.7	153
8	Piston speed, in feet per minute	151	153	154.55	157	155	159.74
9	Mechanical efficiency, percentage	92.6	93.6	88.8	86.8	87.3	89.15
10	Steam per indicated horse-power per hour, in pounds	10.88	10.64	10	10.90	10.53	10.01
11	British thermal unit per indicated horse-power per min., approx.	218	206	196	221	217	208
12	Dry coal per indicated horse-power per hour, in pounds	1.34	1.23	1.18	1.52	1.30	1.42
13	Combustible per indicated horse-power per hour, in pounds	1.19	1.12	1.05	1.19	1.14	1.07
14	Duty per 1 000 lb. of steam	156 602 731	157 133 021	161 676 942	157 060 267	163 104 857	174 735 801
15	Duty per 100 lb. of coal	137 502 733	150 592 270	149 067 802	130 517 109	132 607 122	150 971 958
16	Duty per million British thermal units	140 000 000	149 800 000	149 500 000	136 138 875	133 700 812	151 404 917
17	Kind of coal	Maryland Smokeless. Juniper Lump.	Pocahontas.	Maryland Smokeless.	Maryland Smokeless.	Maryland Smokeless.	Maryland Smokeless.
18	Calorific value of coal, in British thermal units	(Ave.) 13 500	14 260	14 191	14 368	13 531	14 213
19	Percentage of ash	13.25	8.82	10.98	9.3	10.7	8.17
20	Temperature of feed water	56°	100°	106°	105°	101°	102°
21	Actual evaporation per lb. of coal	8.46	9.53	9.17	8.26	8.05	8.57
22	Evaporation from and at 212°, in lb.	10.75	10.91	10.38	9.56	9.48	10.11
23	Efficiency of boilers, percentage	75.54	73.90	72	66.35	68.18	67.76

NOTE.—This table is condensed and rearranged from *Engineering News*, May 26th, 1904.

fairer to the engine builder than a coal test, as there are so many elements of uncertainty entering into coal tests, which are beyond the engine builder's control, but with the wide variation in steam pressures, and, especially, on account of the increasing use of superheated steam, the measurement of economy in terms of steam becomes less definite, and the desirability of conducting pumping-engine tests according to the B. t. u. method proposed by the American Society of Mechanical Engineers, cannot be too strongly urged.

Owing to the variation in "head" under which different pumps operate and which has an important bearing on the mechanical efficiency of the engine, the B. t. u. per i. h. p. per min. best expresses the true economy and renders comparisons easy between various tests.

The criticism is occasionally made that the high duties shown on tests are not maintained in regular service, and, while it is not to be expected that conditions will be kept at the same high pitch as those which prevail during a test, any marked falling off in duty is usually traceable to changed operating conditions.

Where the duty is based on coal there are many opportunities for loss, for while there is comparatively little difference in the efficiency of various types of boilers when operated under proper conditions, there may be a marked loss in efficiency when operated at much above or below the normal rating.

As far as the engine itself is concerned, there is no good reason why its steam economy should not be maintained at, practically, the maximum if the steam and water pressures, for which it was designed, are maintained.

The tendency, particularly of smaller cities, is to purchase larger engines than their immediate requirements warrant, and to stipulate higher test pressures than are ordinarily carried, and as the builder must design so as to obtain the highest economy under these conditions, the result is that, in regular operation, the engine is much under loaded and correspondingly uneconomical.

The question of speed is not so important as pressure, for tests have shown that an engine, running at one-half its rated capacity with normal steam and water pressures, will show from 90 to 95% of its maximum economy.

In some of the larger cities, such as Boston, Louisville, Milwaukee, etc., where the equipment is modern and the conditions such that the engines can be operated under fixed conditions, the yearly duties are maintained at the surprisingly high figures of from 120 000 000 to 135 000 000 ft-lb. per 100 lb. of coal burned for all purposes.

The variation in duty between the best plants is due largely to the quality of coal burned, and the engines can be considered as consuming about 12 lb. of steam per i. h. p. per hr., which, with coal evaporating 8 lb. of water, gives 120 000 000 duty, with $8\frac{1}{2}$ lb. evaporation, 130 000 000 duty and with 9 lb. evaporation, 135 000 000 duty, or approximately $1\frac{1}{4}$ to $1\frac{1}{2}$ lb. of coal per i. h. p.

In the best plants the cost of raising 1 000 000 gal. 1 ft. high ranges from $2\frac{1}{2}$ to $3\frac{1}{2}$ cents, according to the price of coal in the locality, the fuel representing about one-half the cost of the lower figure and two-thirds of the higher.

It will be seen from Table 1, that during the past ten years the duty of pumping engines has been increased from 154 000 000 to above 178 000 000, and the steam consumption reduced from $11\frac{3}{4}$ to $10\frac{1}{3}$ lb. per i. h. p., a gain of over 10%, the coal consumption being brought down to a minimum of 1 lb., and under working conditions to $1\frac{1}{4}$ lb. per i. h. p. per hr.

While the efficiencies are now very high, it cannot for a moment be conceded that the limit has been reached, but the question arises as to what direction to look for further advances. Will it be through further perfecting the present types of engines, or from radical changes in type, such as the adoption of the steam turbine or gas engine?

Prophecy, which is always dangerous, would be particularly so at the present time when such rapid strides are being made in all branches of engineering, and the following paragraphs are to be taken merely as the writer's view based on the present development and tendency of power engineering.

So far as the present type of engines is concerned, it must be admitted that a very steep part of the efficiency curve has been reached, so that comparatively small increase in economy, due to improving the construction of the engine itself, can be expected, for the engines utilize the steam almost to the limit of possibility,

the valve gear giving practically perfect steam distribution, the clearance being reduced to a minimum, and the jacketing system being extremely efficient, and it seems necessary to look into matters beyond the engine for any marked advance in economy. It is probable that superheated steam will give an increase in coal economy of 5% and possibly 10%. Superheat is usually credited with much greater increase in economy than these figures, but it must be considered that superheat shows its greatest gain when used in engines of ordinarily fair economy, while in the case of pumping engines, superheat is applied to machines of the very highest grade, where internal losses and condensation have been reduced to a minimum by the use of multi-expansion cylinders, steam jackets, etc.

Another promising possibility for increasing the economy of pumping engines is by superheating the receiver steam by passing it through reheaters placed in the smoke flues of the boilers.

This idea, while a very old one, has seldom been applied, the late George H. Corliss having used it in a modified form some twenty-five years ago, and it has been applied more recently to a pumping engine at Haverhill, Mass., in the latter case showing a very marked increase in the economy.

While this apparatus will not affect the thermal efficiency of the engine, it will increase the net efficiency of the plant, which, after all, is the only point of practical value to water-works managers.

Some increase in economy may be obtained by the use of higher steam pressures, but this gain will probably be comparatively slight unless coupled with the introduction of the quadruple-expansion engine.

The quadruple-expansion machine does not seem likely to come into use for pumping, the present three-cylinder triple is so perfectly adapted to the direct driving of the three-plunger pump, that there seems to be no warrant for the increased cost of the four-cylinder machine.

Turbo-Centrifugal Pumps.

The remarkable progress being made in the adaptation of the steam turbine to all classes of work naturally brings it into notice as the possible pumping engine of the future, but, from the writer's

point of view, it does not seem likely that it will supersede the reciprocating engine for ordinary water-works service, although it will doubtless find a field where it can be used to advantage under special conditions.

It must be used in connection with a centrifugal pump which, while it has been considerably improved in detail and adapted for pumping against much higher heads than were formerly considered practicable, still remains relatively an inefficient machine.

Centrifugal-pump efficiencies of 80% have been obtained under test conditions but the makers seldom, if ever, guarantee over 70%, and when the loss of the motor is taken into account the net efficiency is probably not much over 60 per cent.

Professor A. Rateau in a paper recently read before the American Society of Mechanical Engineers, gave the mechanical efficiency of a number of turbo-centrifugal pumps at from 34 to 46%, and gave the following figures as indicating what could be expected of an ideal turbo-centrifugal water-works pump:

Delivery in gallons per minute	5 200
Height to which the water is raised	460 ft.
Actual horse-power in water raised	730 b. h. p.
Combined efficiency, including condenser	46%
Pressure of steam in pounds per square inch	210
Vacuum at the exhaust	28 in.
Superheat in the steam	100°
Consumption of steam per brake horse-power in water raised	15 lb.

It will be seen that with steam at the high pressure of 210 lb., and, in addition, superheated 100°, the steam consumption is 15 lb. per pump horse-power.

In a recent test of the De Laval turbo-centrifugal pumps by Professors Denton and Kent a mechanical efficiency of 75% was attained, the steam per pump horse-power ranging from 40 to 32 lb. per hr., equivalent to a duty of from 37 000 000 to 62 000 000 ft-lb. per 1 000 lb. of steam.

As the best American pumping engines in operation to-day, working with comparatively low steam pressure and without superheat, require only about 12 lb. of steam per pump horse-power, and,

with the steam pressure and superheat mentioned by Professor Rateau, would only require from 10 to 11 lb. of steam per pump horse-power, it appears that their economy is from 20 to 25% better than the best theoretical economy attributed to steam turbines under similar conditions.

The centrifugal pump is particularly adapted to the handling of sewage, or water containing a large amount of solids such as would choke the valves of the ordinary pump, and, in localities where fuel is very cheap, might, on account of its lower first cost, be advantageously used where a large quantity of clear water is to be raised to moderate heights, but in permanent plants where the service is at all continuous and where fuel is an appreciable item, it would seem that the plunger pump will continue to be the most economical unless the efficiency of the turbo-centrifugal is increased at least 25 per cent.

Gas Engines.

The gas engine undoubtedly offers greater opportunities for economy in fuel than any other type of motor, but there are some things which stand in the way of its general adoption in municipal pumping plants.

Perhaps the greatest obstacle is the lack of a satisfactory bituminous coal-gas producer, but as a great deal of work is being done along this line, it is to be expected that a satisfactory producer will ultimately be designed.

The large gas engine, while in successful use in many places, can hardly be said to have entirely passed the experimental stage, and it is to be expected that its adoption will proceed slowly until its design has narrowed down to certain fixed lines.

The rather high speed of the gas engine and its lack of flexibility are points against its adoption for water-works service, excepting for reservoir pumping where a fixed speed can be maintained.

For small pumping plants, particularly auxiliary ones where the cost of gas consumed is so small as to more than offset the increased cost of attendance of the steam pumping plant, the gas engine already has a field.

As to economy, the gas-engine builders aim to produce 1 h. p. per hr. on 1 lb. of coal, which is about the best figure reached under test conditions by modern pumping engines, and 25% better than is

ordinarily attained even by first-class steam pumping engines, but there is some question as to whether the gas engine can maintain as low an average as 1 lb. of coal throughout the year, so that it may be fairly accepted as a fact that the very best steam plant that can be built will produce 1 h. p. with practically the same quantity of coal as a gas engine and producer plant.

If this is the case, it then becomes a question of the first cost of the two plants and the cost of attendance, repairs, depreciation, etc.

In brief, it is the writer's opinion that within the next ten years the economy of the present types of pumping engines may be increased about 10%, due to the use of higher steam, superheat and the utilization of the heat in waste gases, and that within that time there is little likelihood of either the steam turbine or the gas engine superseding the reciprocating steam engine in general water-works service.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS, 1904.

DISCUSSION ON PUMPING MACHINERY.

By Messrs. Carl George de Laval, W. F. M. Goss, R. C. P. Coggeshall, H. F. Dunham, Richard J. Flinn, Elmo G. Harris, W. B. Gregory, George Higgins, James Alex. Smith, J. N. Chester, Charles A. Hague, J. T. Fanning, M. L. Holman, G. O. M. Olsson, Otto H. Mueller, William Mayo Venable and Irving H. Reynolds.

Carl George de Laval, Esq., East Cambridge, Mass. (By letter.) Mr. de Laval. —Referring to Mr. Reynolds' paper, it is indeed gratifying to see such a carefully tabulated record of the various types of pumping engines in use in the United States. It certainly represents the acme of perfection in this type of machine in which higher duties have been reached than in any other class.

The author, however, under "Auxiliaries," does not treat this part of the subject correctly. The fallacy and wrong impression which result from forming an opinion of the economy of auxiliaries by taking the weight of steam used per indicated horse power per hour as a basis of measurement are very apparent; for instance, a recent official test of an engine shows that while the steam per indicated horse power per hour of the air pump was 142.2 lb. and of the main engine, 13½ lb., the heat recovered from the exhaust from the air pump made it equal to the main engine in economy. This is also confirmed by the discussion on the economy of the auxiliaries of U. S. S. *Minneapolis* in the *Journal* of the American Society of

Mr. de Laval. Naval Engineers of February, 1898, and also in *Revue de Mécanique* for May, 1898, where attention was called to the economy of auxiliaries used in connection with proper feed-water heaters. The claim was made that about 1 000 thermal units per pound of steam could be recovered from the exhaust, and it was shown that, by such an arrangement, the economy of an independent pump was equal to that of the main engine, besides having all the advantages of a separate pump.

In the engine referred to, the weight of steam per indicated horse power per hour for main engine was 13.68 lb., and for air pump was 138 lb.

British thermal units utilized in work per pound of steam for main engine	186.8
British thermal units utilized in work per pound of steam for air pump	18.3
British thermal units lost per pound of steam in exhaust for main engine	919.6
British thermal units lost per pound of steam in exhaust for air pump	139.9
British thermal units recovered per pound by heater, main engine	46.1
British thermal units recovered per pound by heater, air pump	994.3
British thermal units given to each pound of steam in boiler for main engine	1152.5
British thermal units given to each pound of steam in boiler for air pump	1152.5
British thermal units per indicated horse power per minute, main engine	251.82
British thermal units per indicated horse power per minute, main air pump	365.88
Indicated horse power, engine	1983.7
" " " air pump	22.0
Ratio of heat used by the air pump to that used by main engine	0.0161
Ratio of heat used by the air pump to the total amount of heat used	0.0158
Ratio of i. h. p. of air pump and main engine, $\frac{22}{1\,983.7}=$	0.011

Now 138 lb. per i. h. p. per hour of the air pump would frighten most engineers; but, when we reflect that the horse power of the air pump is always very small compared with that of the main engine, and that much of the heat in exhaust from auxiliaries can be recovered in the feed-water or in any one of the cylinders of any

Mr. de Laval.

multi-cylinder engine, the entire aspect is changed, and it is seen at once that the independent auxiliaries are not such wasteful machines as supposed and stated in the paper. The independent auxiliaries can be used to much better advantage, as they can be run according to the speed required and their capacities can be gauged accurately. It is hardly possible to proportion the air pump exactly to the work to be done when it is run directly from the engine, which is one of the greatest disadvantages in operating a plant successfully, as the air pump will always have to be run in a fixed ratio of speed to the main engine.

In the good old days of James Watt, it was customary to make the air pump bear a certain fixed ratio to the volume of the larger steam cylinder of the main engine, and this is still followed by many, and means, in many cases, an unnecessarily large pump for the work to be done under normal conditions. Herein lies one of the advantages of independent auxiliaries, particularly of the air pump, because it can be made sufficiently large and, in fact, larger than necessary for the regular work, to suit those of conservative views, and can be run at any speed to agree exactly with the work to be done.

It is of the utmost importance to bear in mind that we are dealing with heat engines and we must not for a moment lose sight of this fact. Eminent engineers in all parts of the world have been, and are still, calling attention to the fact that to rate the performances of steam engines upon weight of steam used is misleading in most cases. Tests show clearly and in simple language the fallacy of comparing various types of engines on the basis of steam end per indicated horse power per hour; take, for example, the report of the test of one of the most recent and well-known engines using superheated steam and that of an equally well-known and successful engine using saturated steam as ordinarily employed. It has been shown that while the first is debited with 10.02 lb. and the second with 11.3 lb. of steam per i. h. p. per hour, when the engines are considered with reference to the quantity of heat used, it is found that the former required 3 281.5 kalories and the latter, 3 307.75 kalories per i. h. p. per hour, or practically the same quantity of heat, and this without the many troubles accompanying the use of superheated steam. Numerous examples could be cited.

Another error is committed in deducting bodily all the moisture supplied with the steam and asserting that the engine used a certain quantity of dry steam per horse power per hour, an absolutely unscientific and meaningless statement. This moisture, although detrimental to economy, carries heat to the engine, and this heat should be charged to the engine since there is no known law that enables us to determine exactly the loss due to such moisture.

Mr. de Laval. When treating the engine as a heat engine all heat must be taken into consideration, because on this alone can an opinion be formed.

In reference to the question of speed, there is no doubt but that the positively controlled pump valves were placed on the market on the basis of a commercial advantage and nothing else, because, in many instances, the positive valve gear has been removed from pumps fitted with same, and the pumps have been operated with equally good success without the gear. An instance of this is a pumping engine designed by the writer, which has positive valves running at a speed of 600 ft. per minute, and the valve gear was entirely removed as an experiment to determine the capability of the engine running at same rate of speed without it. On account of the successful operation of the pump without the positive valve gear, it has now been running continually for three years, with very slight alteration in arrangement of the valves themselves. The results have proven conclusively that high-speed pumps do not require positively controlled valves, as various engines have been designed and are running with speeds of 600 to 800 rev. without such attachment, showing that the water hammer caused by the backward flow at the end of the stroke, which causes the valves to seat hard, can be remedied without the application of mechanically moved valves, if properly designed in relation to water space, air-chambers, etc.

There is no doubt but that a high-speed pump possesses advantages in relation to less cost and less space occupied than a slow-speed pump with a piston speed of 200 ft. Still it is true that the pump end will remain practically the same in size, the steam end, however, can be reduced in size and weight. There will be no more wear and tear on the high-speed pump than on the slow-speed pump, if the velocity is properly proportioned. On several engines of the high-speed type, the renewals and repairs have been no greater than on a slow-speed pump. There is no question but that the high-speed engine should give somewhat better economy than a slow-speed engine. The results, as tabulated, are comparisons for speeds on an engine that was designed for slow speed and run at high speed and do not represent the results that would have been obtained if an engine of the same capacity had been designed for high speed. The two items, high speed and high steam pressure, will be the requirements in the future for economical engines, and, at present, there are enough of them in daily service to insure an increasing demand. When water is once in motion it is not a question of speed in feet per minute, but of changes of plungers or rotative speed, and these changes do not affect any other part of the pump end except passages and valves, which always should be made amply large to allow a low velocity per second. The high speed produces smaller moving parts,

which are less cumbersome, more flexible, and easier to handle than the large parts of slow-speed engines, and will also insure easier making and stronger shapes with less metal than can be found in slow-speed pumping engines. Mr. de Laval.

W. F. M. Goss, Esq., La Fayette, Ind.* (By letter.)—The writer would suggest that progress in the development of the pumping engine, which is so well set forth by Mr. Reynolds, is practically coincident with progress in steam-engine design. The fact that a pumping engine operates under conditions favorable to experimentation has long been recognized. The constancy of its load and the presence of an abundant supply of water for condensers have done much to make the pumping station an ideal steam-engine laboratory. Not only have tests of pumping engines been more numerous than those of other types of engines, but the data obtained from them have usually possessed a higher degree of accuracy. One result of this process of testing and study is to be seen in the progressive record set forth by the paper, and another equally important result is to be found in the influence which the knowledge thus obtained has exerted upon the design of engines of other types. Herein is a high tribute to the expert engineer, the extent of whose achievements is well indicated by the results which the paper makes of record. Prof. Goss.

R. C. P. Coggeshall, Esq., New Bedford, Mass.† (By letter.)—Regarding the paper by Mr. Reynolds, the writer would say that in Table 1, No. 17, the New Bedford engine designed by E. D. Leavitt, M. Am. Soc. C. E., is listed as a "vertical triple." There should be listed in place of this, two "vertical compound" engines each of 10 000 000 gal. capacity.‡ The two engines are duplicates and in general arrangement are rights and lefts. They appear to be equally efficient. Mr. Coggeshall.

On page 514, the Louisville engine (No. 2, Table 1) is stated to be notable as holding the record for a compound engine "having given an average annual duty of about 120 000 000 ft-lb. per 100 lb. of coal." The writer calls attention to the fact that the New Bedford plant has shown an annual duty surpassing 130 000 000 ft-lb. per 100 lb. of coal burned for all purposes, and this with an inferior quality of coal. Should we not be credited with holding the leading record for a compound engine?

The temperature of the flue gases as they pass into the chimney is 425° fahr. It would seem as if here was a waste of heat which later might be utilized in further raising the duty of the plant.

When the plant was contemplated we were persuaded that the work of a compound engine of correct proportion and proper de-

* Dean of the Schools of Engineering, Purdue University.

† Supt. of Water-Works.

‡ Note by Editor.—This table has since been changed by Mr. Reynolds.

Mr. Coggeshall. sign would so nearly approach the duty which would be obtained by a "triple expansion" similarly located, that it would not be worth while to pay the extra cost of a "triple expansion." We think the result has justified our decision.

Mr. Dunham. H. F. DUNHAM, M. AM. SOC. C. E., New York City. (By letter.) —The difficulty of securing economical pumping machinery in small units has not been exaggerated in Mr. Reynolds' paper or in the discussion. Aside from economy, there are existing conditions that cannot well be disregarded. Many water-works stations have been so located that the floor line is close to high-water mark and cannot easily be lowered. On account of the growing demand for a better quality of supply, changes to ground or deep-well water are often desirable, and it is a distinct advantage to have the working parts of new pumps at a lower elevation while, in general, the same floor level is maintained. Many water and electric light plants are being combined, at least in operation, and in such cases power from high-duty Corliss engines is available both day and night.

Such considerations arising in his practice, led the writer to design a pump, or pumping machine, suitable in some measure for adaptation to varying conditions. It is shown in one of its sizes in Plate XXXVII. One installation is outlined in Fig. 18. Figs. 19 and 20 show section and plan. One-half or side may be directly connected to a shaft. It will be noticed that cylinders and valves can be placed at a low elevation as indicated, or still lower by increasing the height of the A-frames. All valves and other portions are easily accessible. One side or half can be operated separately while the opposite side is being overhauled. Passage-ways for water are ample, and there are no large water chambers that require proportionately heavy castings.

This design variously modified to meet local conditions has been installed and is in successful operation in several cities, in one instance, driven by a water-wheel, in another by a small Corliss engine, as shown. In other cases, in connection with electric light and power plants, it is driven from main line shafting run by compound condensing Corliss engines of 600 h. p. or more, with results in economy that will be evident when the extreme simplicity, smooth running, and actual energy per million gallons necessary to deliver water under pressure are considered. It is adapted to gas engine, electric, or other motor service. It runs well against fire pressures. Direct-acting, compound-condensing pumping engines are not in the same class for economy.

When the low first cost is also considered, there is encouragement for the belief that small cities may be supplied with water at an expense per million gallons for pumping, not much if any below the prices common in many larger cities. The design introduces

Mr. Dunham.

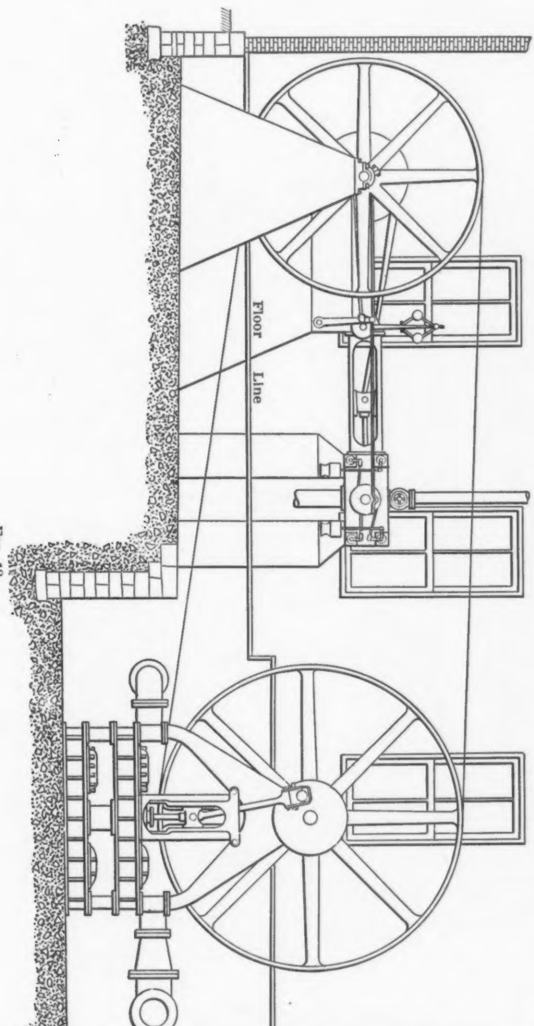


Fig. 18.

Mr. Dunham.

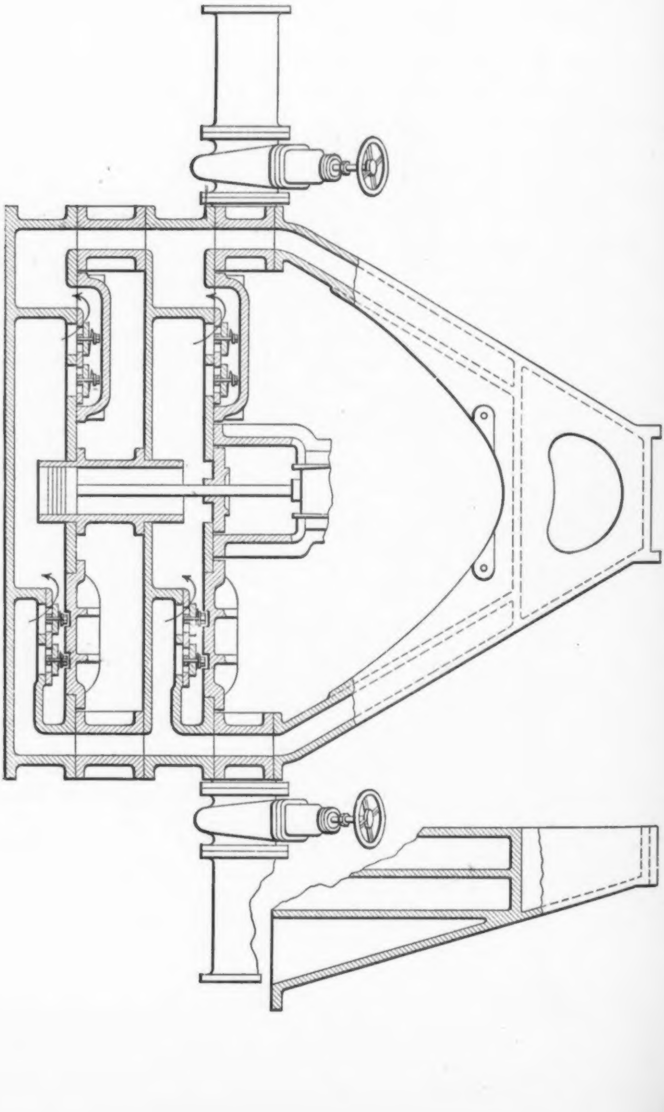


Fig. 19.

Mr. Dunham.

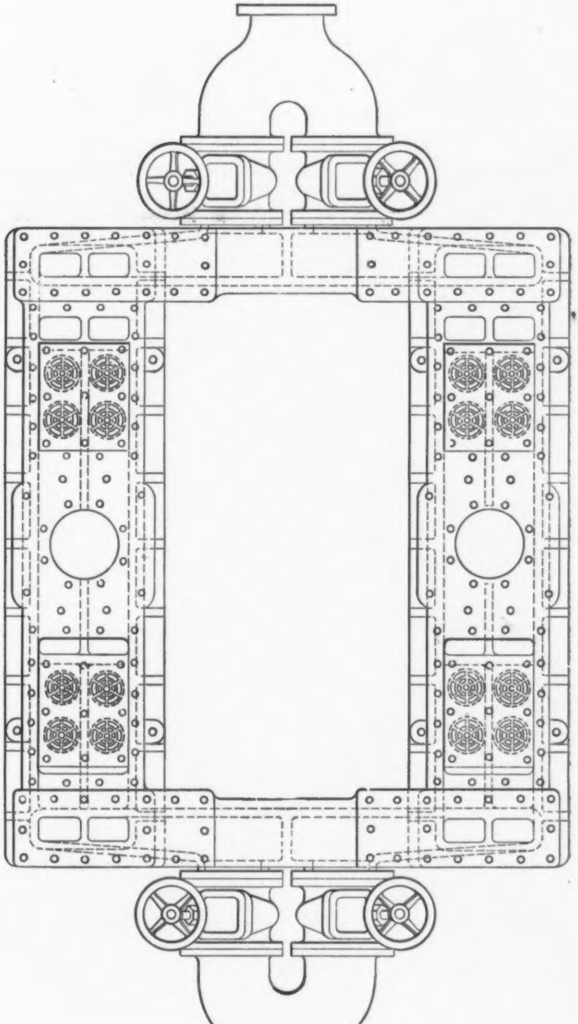


FIG. 20.

Mr. Dunham. a belt or drive, it is true, but in many places and many kinds of business properly proportioned belts are used and are satisfactory for more severe service than it is necessary to impose when installing machinery for the water supplies in question. There is no better proof of these advantages than actual demonstrations afford.

Mr. Flinn. RICHARD J. FLINN, ESQ., Boston, Mass. (By letter.)—High duties and efficiencies of pumping engines are obtained only by the careful consideration of all details, no matter how small. Mr. Reynolds states that, as far as known, the 30 000 000-gal. Allis engine at the Chestnut Hill Station of the Metropolitan Water Board, Boston, holds the record for general efficiency. This engine, as well as the St. Louis Allis pumping engines, use the "Flinn" system of distribution of steam for the jackets and receivers, as shown in Fig. 21. This system was devised by the writer in 1897 and has the effect of

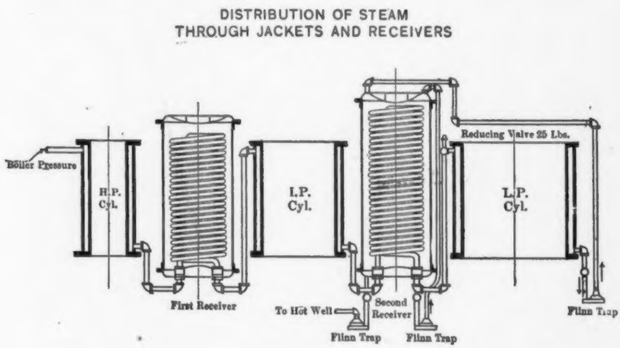
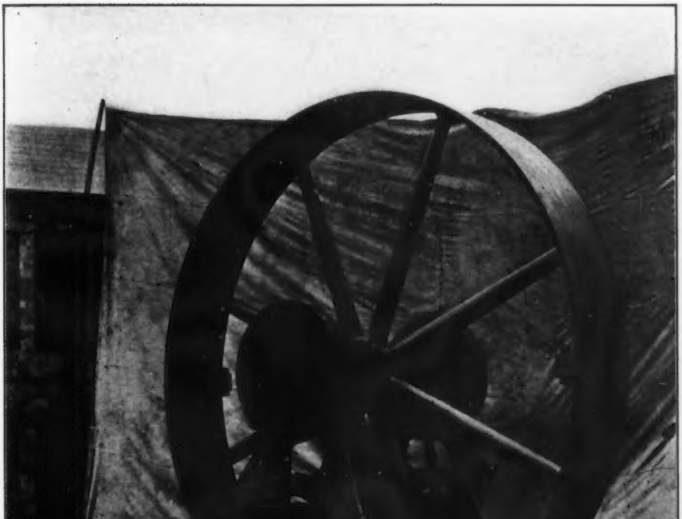


FIG. 21.

reducing the quantity of jacket steam used by about 20 per cent. Another method of using this system is shown in Fig. 22. The system consists in taking the water of condensation from the jackets by Trap No. 1 and, instead of returning the same directly to the boiler, it is discharged into an expansion tank connected with the receiver placed between the high and intermediate pressure cylinders. The water being discharged into the tank at a temperature above that due to the pressure in the receiver, a portion of the water evaporates into steam and assists in driving the second cylinder. Trap No. 2 takes the water from Tank No. 1 and discharges it into Expansion Tank No. 2, connected with the steam receiver between the intermediate and low-pressure cylinders, where a portion of the water evaporates and assists in driving the low-



POWER PUMP.

pressure cylinder. The water from Tank No. 2 is discharged into the feed tank. Mr. Flinn.

The water supplied to the boiler is equivalent to the steam going out to the engine, and it is apparent that the steam required from the boiler to develop a given horse power will be reduced by that obtained from the jacket water. At the same time, the boiler loses the excess of heat in the jacket water above that due to atmospheric pressure, which it would get if the water was discharged directly into the boiler, and the fuel account would not probably be reduced below that due to putting the jacket water directly back to the boiler. In other words, in cases where the layout of the plant is such as to enable the water to be drained directly back to the boiler, there is, of course, no gain in fuel due to this system, though there is a gain in water consumption; and where, as is customary, engines

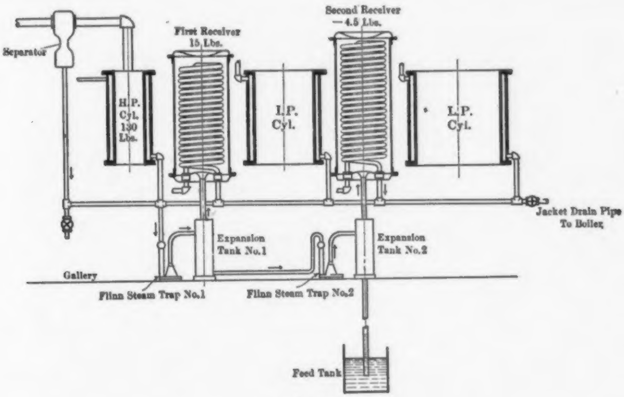


FIG. 22.

are installed based on the water consumption, the system gives an obvious advantage to the contractor. In cases where the water from the jackets is rejected to the sewer or run into an open hot-well, so that its excess of heat above that due to the pressure of the atmosphere is lost, there is an obvious gain in the fuel account.

This same system has been applied to compound-engine jackets in other ways. In one experiment, using this system, Trap No. 1 was discharged into the top of the low-pressure jacket, the drain pipe of the low-pressure jacket being connected with Trap No. 2. The steam from the water discharged into the low-pressure jacket was found sufficient to maintain a pressure of 6 lb. per sq. in. in the jacket.

Prof. Harris. ELMO G. HARRIS, M. AM. SOC. C. E., Rolla, Mo. (By letter.)—Any effort to discover and publish the correct principles of the design of centrifugal pumps (or "velocity" pumps in general) should be welcomed, for, up to a very recent date, this important branch of applied mechanism had been strangely neglected.

Mr. Venable's preliminary mathematical treatment would have been more readily understood had he shown the propeller and circumference of the wheel on Figs. 1 and 2. For instance, the definition of the angle, β, is not complete, but if the vane had been shown there would have been evidence that it is the angle between the u and the path of the stream relative to the revolving wheel.

The writer cannot see that the statement on page 475 of Mr. Venable's paper is accurate. Suppose the runners are revolving and full of water, but not discharging, then the pressure will increase from the center out, regardless of the cross-section of the runner. Mr. Venable seems to have misapplied Bernoulli's theorem (that pressure head + velocity head = constant). The definition of centrifugal pumps (page 491) is meaningless. It refers only to construction, and to only one of the great variety of constructions.

Evidently much of Mr. Venable's discussion applies only to very low lift pumps, which have correspondingly low velocities; but he does not so qualify it. Fig. 9, and the discussion thereof, would be absurd if the object were to secure high lifts.

On page 495, Mr. Venable declares in favor of "a vortex chamber of ample size, to allow the effect of the pulsations at the tips of the vanes to be dissipated." Pulsation in a centrifugal pump, or fan, is evidence of bad design.

It is the writer's opinion, that the greatest loss of energy in the operation of centrifugal pumps occurs just outside the tips of the vanes while the velocity of rotation is being checked in the "volute," "vortex chamber," or "whirlpool chamber," as it is variously styled.

In a paper presented in 1903,* the writer attempted to make this clear, and proposed some remedies; among them the device, used now in most high-class, high-lift pumps, which receives the water from the tips of the vanes in numerous discharge passages, flaring outward and emptying into a relatively large receiving chamber, the duty of which is only to conduct the water at slow velocity to the main discharge pipe.

The writer believes that "too much algebra beclouds the intellect," and though guilty of injecting some algebra into the paper before-mentioned, his later studies have all been in simplifications of the mathematics and of the construction.

The writer would now state the problem for the designing engineer thus:

* "Theory of Centrifugal Pumps and Fans," *Transactions*, Am. Soc. C. E., Vol. LI, p. 166.

First.—Get the water into rotation within the wheel with the least possible eddying, or contention of currents. By this is meant, intermingled currents of water having different velocities and directions. Comparatively little energy is lost by water moving against a hard impervious surface. Hence we can consistently allow high velocities over smooth surfaces when the areas are small, as in pumps. Prof. Harris.

Second.—Give the interior of the wheel, in which water revolves, such a volume and radius that the water will all come to one state of pressure and motion as it passes from the tips of the propellers. This cannot be realized in impulse pumps where the radial length of the passage is short and the velocities are great.

Third.—Introduce air between the back of runner and the fixed casing, thereby reducing friction and preventing water from getting to the journals and glands.

Fourth.—Check the velocity of the water as quickly as possible after it escapes from the propellers, without allowing vortices or a whirlpool to form outside the runners, and without allowing water with great velocity to pass into or against water with little velocity. The importance of this condition can be judged by the fact that one-half the energy in the rotating water is due to its velocity, and the greater part of this will be lost unless the velocity is gradually but quickly reduced, and that without conflicting currents. It is a neglect of this that explains the fact that the majority of centrifugal pumps—of the old class—give efficiencies of less than 50 per cent.

Fifth.—If the pump is to operate with varying discharges, or under varying heads, either alone or combined, its discharge must be adjustable independent of speed. This condition has been wholly neglected in the past—an almost incredible fact. This requirement is the more important from the fact that it is difficult to get a satisfactory formula for discharge, and, therefore, a pump, otherwise satisfactory, may give too great or too little discharge unless made adjustable. Again, since, in the present state of the art, it is difficult to predict accurately the speed necessary to get the head, and, if not adjustable, the discharge will vary with the speed, we see the further necessity of making the discharge adjustable.

The writer knows of one large installation of late design that, when tested, fell below the guaranty, 45% in discharge, and 15% in efficiency; another, in which the runner is 14 ft. 6 in. in diameter, remained unpaid for after twelve months' trial, because it had not given guaranteed results; and a third, which is extraordinary for its size and notoriety, and which is of the latest design, is giving very nearly half of the guaranteed pressure, though running at the specified rate. Backed by these facts, are we not

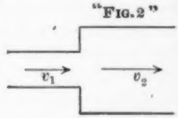
Prof. Harris. justified in saying that the present state of the art of designing centrifugal pumps is unsatisfactory?

Prof. Gregory. W. B. GREGORY, ESQ., New Orleans, La.* (By letter.)—The writer does not wish to enter into a discussion of the merits of Mr. Venable's paper or of the soundness of the theories advanced. He wishes, however, to call attention to an error in Appendix I. The author has misquoted Professor Unwin in regard to head lost due to a sudden enlargement of section. Professor Unwin says:†

"A stream of water moving with the velocity v impinges] on a stream moving with the less velocity v_2 in the same direction, so that there is an abrupt change of velocity from v_1 to v_2.

"Then there is a loss of pressure, which measured in feet of head, is equal to the head due to the relative velocity $v_1 - v_2$. That is the head lost is $\frac{(v_1 - v_2)^2}{2g}$. Fig. 2 shows a passage in which such an abrupt change of velocity would occur. If the change of section were gradual, the gain of pressure in the second part of the passage would be by the last theorem $\frac{v_1^2 - v_2^2}{2g}$ feet of head. Deducting from this the head lost, the actual increase when the change of section is abrupt is

"FIG. 2"



$$h_2 - h_1 = \frac{v_1^2 - v_2^2}{2g} - \frac{(v_1 - v_2)^2}{2g} = \frac{(v_1 - v_2)\,v_2}{g}.$$

"The loss of head is due to the dissipation of energy by the irregular eddying motions generated in the stream and to prevent all loss from this cause the change of section must be very gradual."

The author's experiments confirm the theory as given by Professor Unwin. Let us take a case in which $v_1 = 10$ ft. per sec. and $v_2 = 6$ ft. per second. The gain of head equals

$$\frac{(v_1 - v_2)\,v_2}{g} = \frac{(10 - 6)\,6}{32.2} = 0.745 \text{ ft.}$$

It is somewhat difficult to understand how a blunder of this kind was made by Mr. Venable.

Mr. Higgins. GEORGE HIGGINS, M. INST. C. E., Melbourne, Victoria. (By letter.)—The writer wishes to call in question the demonstration given on pages 475 and 476 of Mr. Venable's paper.

Frictionless liquids and surfaces are under consideration. An infinitesimal stream of liquid, bounded by a frictionless surface, moves in a mass of the liquid. Now, if there is no friction, there is no change of pressure occasioned by this movement; consequently it is difficult to understand the author's meaning when he states, with reference to the quantities in Equation III, that "This must be the pressure head produced by the motion of the channel."

* Asst. Prof. of Experimental Eng., Tulane Univ.

† *Minutes of Proceedings*, Inst. C. E., Vol. LIII, p. 250.

As the channel moves, if its axis makes any angle except 90° with the direction of motion, there will be a flow through it. The liquid, in flowing through the channel, may be considered as having a velocity which is the resultant of u in the direction of motion of the channel and v relatively to the channel. In Fig. 23, let A O and A B represent u and v_r, respectively, in direction and magnitude; then, completing the parallelogram, A D represents the resultant velocity, which we may call x, in direction and magnitude. Using Mr. Venable's notation, x may be resolved into w, normally to direction of u and v in the direction of u. Mr. Higgins.

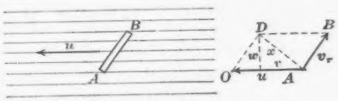


FIG. 23.

As no pressure will be caused by the motion, the energy imparted to the W pounds of liquid, which pass through the channel per second, $= \frac{w}{g} \frac{x^2}{2}$. In other words, the head acquired by the water by [this movement of the channel in a straight line is simply the velocity head

$$\frac{x^2}{2g} = \frac{w^2 + v^2}{2g}.$$

Of course, if a closed channel were moving round in a circular path instead of in a straight line, then there would be pressure due to centrifugal force, the amount of which may be shown to be $\frac{v^2}{2g}$.

JAMES ALEX. SMITH, ESQ., Melbourne, Victoria. (By letter.)— The writer has devoted considerable attention to the theory of the centrifugal pump, and would have desired to collate various data for the purposes of this discussion, but the time available is so extremely limited that only the most salient points can be referred to. Mr. Smith.

It is gratifying to find that many of the deductions developed in Mr. Venable's valuable and instructive paper accord with those arrived at by the writer by entirely different analyses.

The present discussion is confined to a consideration of the runner; in a sense, the most important and, perhaps, least understood element.

Two false quantities will very frequently be found underlying published theories; if these be eliminated from the mental attitude, various obscurities are readily elucidated.

I.—The assumption is made that whatever the curvature of the vane, flow must of necessity maintain contact with the surface.

II.—It is assumed that the runner passages are always efficiently full, *i. e.*, that the velocity of flow in, and in relation to, a runner is dependent upon—orbitary—cross-sectional area at any given plane.

Mr. Smith. In reference to (I): Consider a particle of flow in contact with a vane; the particle will, under the influences in action, trace a curve in relation to a fixed plane. At any point the motion is resolvable into two components, and of these one is tangential to a circle concentric with the axis of rotation, and described through the given point.

But tangential motion implies recession from the axis, with dependent tendencies classed as centrifugal. If then at any point the rate of radial recession of a particle, caused by operative "centrifugal" tendencies, impressed at a preceding point, be greater than the rate of radial recession—curvature, for instance—of a vane, then contact will cease and the vane will become at that point inutile.

Inertia of the particle is the sole "abutment." There is no analogue to the external, contact-compelling constraint existing in cases of velocity increment due to solid wedge action.

Thus in a pump, flow may leave the "impelling" vane, cross the channel, and impinge upon the opposite wall of the passage.

Dismissing the fallacious idea, the true condition may be studied.

Upon projectile velocity of the particle, both head and volume of flow ultimately depend.

It may be decided to limit the functions of the runner to velocity acceleration, transforming the resulting velocity energy into pressure energy by appliances external to the runner. Or the design may be such that acceleration, and subsequent retardation, both occur in the rotating element. It is unnecessary to labour the point that acceleration and retardation cannot co-exist.

Dealing with acceleration: Since head and volume are dependent upon projectile velocity, therefore, for a given speed of revolution, the most efficient runner is that imparting a required velocity at the least radius or, expressed otherwise, that in which acceleration in relation to radius is maximum.

Efficiency is here interpreted in the broad sense, covering reduction in first cost and in space occupied, in addition to mechanical efficiency alone. Eliminating journal friction, in centrifugal pumps, the latter quantity is limited solely by stem and internal fluid friction; therefore, it must be shown that decrement of radius does not lead to an undue increment of those factors by introducing, or accentuating, losses due to disturbed flow, or increased frictional contact.

The writer has shown elsewhere* that solution of the problem requires that the accelerative portion of the runner shall be radial.

Contact is then continuous; radial and tangential accelerations are equal, and in each case in direct proportion to the radial incre-

* "Notes on Internal Flow in Centrifugal Pumps, Part II: A Study of the Theory of the Runner." Read before the Victorian Institute of Engineers, June 5th, 1908.

ment; hence, at each instant the particle is impelled in a path cutting the radius at each instant at a constant angle of 45°. As a consequence, the traced curve is the equiangular or logarithmic spiral of 45° spiral angle. Further, acceleration in respect to radius is maximum. Mr. Smith.

Motion is radial in reference to the runner, and the acceleration is uniform, that is, the shortest and least eddy-producing path is followed.

The "spiragraph," illustrated diagrammatically by Fig. 24, was devised by the writer to test experimentally the completeness of the basic data in use.

In essence, the instrument consists of a rotating axis (1) carrying a steel guide (6) shaped to the vane-form to be investigated. A light carriage (5), when released by the detent mechanism (3, 7),

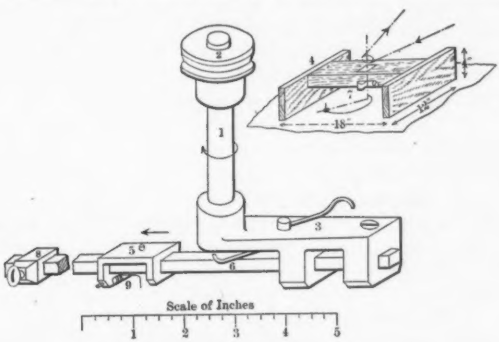


DIAGRAM OF SPIRAGRAPH.

Fig. 24.

moves from the center under causes identical with those governing the motion of a particle of flow. The curve resulting from the combined radial and angular movements is recorded upon the smoked surface of a fixed plane by the light contact of a minute stylus (9).

The curve shown in Fig. 25 was traced at 750 rev. per min. by the carriage moving along a radial arm, but it is to be noted that variations of speed of rotation do not affect the form or properties of the curve. Times of development alone are altered.

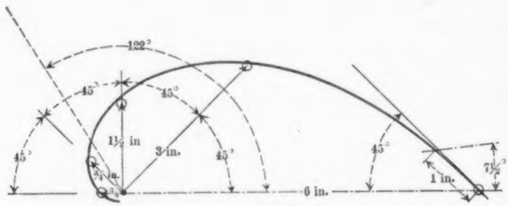
The centers of the small circles are computed comparison points in an equiangular spiral of 45°; the near coincidence of the predicted and observed results is very apparent.

The curve (*c*), Fig. 26, was traced by the use of a guide (*b*), convex in the direction of approach. As before, the centers of the small circles are points of comparison. It will be seen that after a

Mr. Smith point of maximum acceleration has been attained, retardation ensues. Traces on the guide—previously smoked—shew that in consequence the carriage would have left the rod and pursued a free path, had not the concave side restrained it.

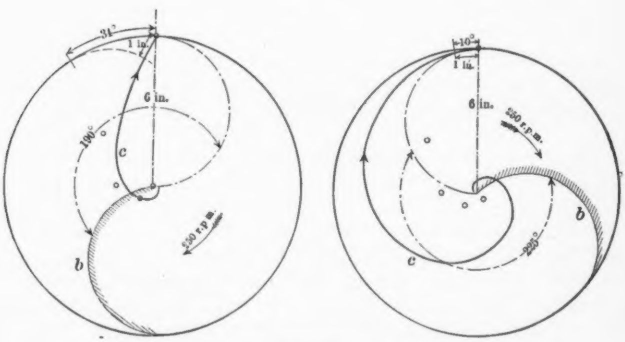
In Fig. 27, the direction of curvature of the guide is reversed; the previous remarks continue to apply, *mutatis mutandis*.

Compare Figs. 25, 26 and 27: The angular motions (and therefore times) necessary to vary the radial distance of a particle, mov-



PATH OF A PARTICLE IMPELLED BY A RADIAL VANE.

FIG. 25.



PATHS DIRECTED BY CONVEX AND CONCAVE VANES.

FIGS. 26 AND 27.

ing in the respective curves, from 1 to 6 in., are 122°, 190° and 225°. An increment of radius from 5 to 6 in. in each case requires, respectively, 7½°, 10° and 34° of angular motion. The final projectile velocities are, sensibly, inversely proportional to the latter angles, or times.

The figures are approximations scaled from actual curves, photographically reproduced in the diagrams.

Fig. 25 demonstrates the relatively great projectile velocity imparted by a radial runner. In Fig. 26, motion is retarded and tends to become radial (pressure head), whilst in Fig. 27, it is toward a circular, radially static, non-useful state approximating to that of a particle in a fly-wheel rim. Mr. Smith.

It follows from first principles, and the experiments show, that, in a frictionless machine, energy imparted to a particle by a radial vane is wholly transformed into kinetic form. The question whether it is legitimate to assume that the condition is utilisable in a centrifugal pump may, however, be raised.

Consider the matter as typified in Froude's well-known experiment: Energy due to a constant pressure head is transformed by a suitable nozzle from the potential to the kinetic form, that is, lateral pressure gradually decreases until at the point of efflux it vanishes. Thus the issuing jet is enabled—in the manner of a solid projectile—to bridge an intervening free space, and enter a second (reversed) nozzle, wherein a converse process of retransformation is effected. The jet remains unbroken until the flow has ascended to a second reservoir at—allowing for friction—the level from whence the fluid descended.

The question is, therefore, answerable in the affirmative, provided velocity-transforming appliances, in unison with the runner conditions, and the jet analogue, are used.

In reference to the erroneous concept (II): A relatively thin flow, considered as composed of particles moving with equal velocities, will, at planes normal to the flow, possess cross-sections inversely proportional to the velocities at those planes. In considerable thicknesses eddy friction is a disturbing factor.

Arbitrary variations of section cannot usefully alter this relation; constriction will reduce output; undue enlargement will not be efficiently filled, and either actual cavitation or energy-absorbing eddies will result.

Each section should be correlated to the velocity imparted by the impelling vane.

To investigate this phase of the question the writer devised a "vorteximeter,"* virtually a glass-sided runner. By rapidly recurrent flash illumination the flow is observed as though rotation did not exist.

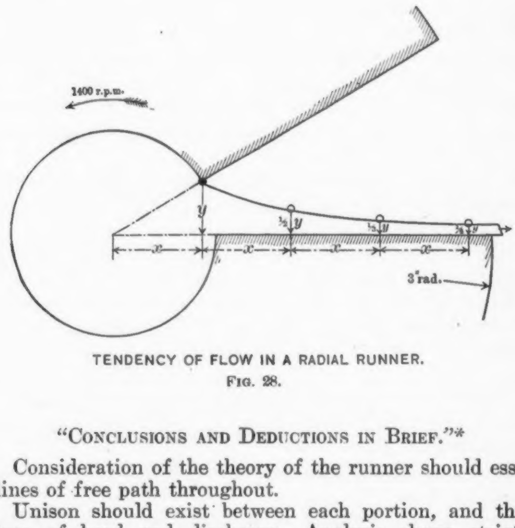
Photographs are readily obtained by attaching pieces of sensitised paper to the rotating runner. The curved line of flow in Fig. 28 was thus secured. In this particular case flow was limited to two dimensions, therefore, width measures cross-sections and, inversely, velocity.

* "Notes on Some Experimental Researches on Internal Flow in Centrifugal Pumps and Allied Machines." Read before the Victorian Institute of Engineers, April 6th, 1902. Reprinted in full in *Engineering*, Vol. 74, p. 762, and in the *Scientific American Supplement*, Nov. 29th, 1902.

Mr. Smith. The centers of the small circles mark width corresponding to the computed effects of a radial vane. They are also closely in accord with the quantities derived from the "spiragraph" curve (Fig. 25) and, within the limits of experimental error, they coincide with the photographed line (Fig. 28).

The unoccupied section of the sector in Fig. 28 visually demonstrates the fallacy of the assumption (II) that flow will conform to arbitrary section.

There are many interesting practical derivations from the simple fundamental principle of finite velocities of flow. Perhaps a quotation of brief deductions, gleaned from a previous paper by the writer, may be of interest here.



TENDENCY OF FLOW IN A RADIAL RUNNER.

FIG. 28.

"CONCLUSIONS AND DEDUCTIONS IN BRIEF."*

"1. Consideration of the theory of the runner should essentially be on lines of free path throughout.

"2. Unison should exist between each portion, and the given conditions of head and discharge. Analysis shows strict interdependence.

"3. Flow in the runner, and in reference to a fixed plane (or in space), must be clearly differentiated.

"4. Head is due, ultimately, to the motion of a particle *in space.*—

"5. Such motion is (here) the result of constant angular rotation and consequent acceleration.

"6. The curve generated is an equiangular spiral of 45 deg.

* Extract from "Notes on Internal Flow in Centrifugal Pumps, Part II: A Study of the Theory of the Runner." Read before the Victorian Institute of Engineers by Jas. Alex. Smith, May 6th, 1903.

"7. Projectile motion in the curve varies as the radius vector—or radius of gyration. Mr. Smith.

"8. Motion in the curve is not co-incident in direction or velocity with tangential or circumferential velocity at the same point. The velocity ratio is, $\sqrt{2} : 1$ to either the radial or tangential velocity.

"9. Computations based upon the assumption of equality may therefore be in error.

"10. It does not suffice to determine the inlet and outlet to a runner and connect them by any arbitrary 'smooth curve;' action is not instantaneous, and intervening parts cannot be ignored.

"11. The form of each portion of the driving vane should be such that it impresses upon the flow the measure of acceleration due to the angular motion of that portion.

"12. The radial vane is complementary to the equiangular spiral and fulfils the required conditions.

"13. The radial path is that of shortest frictional contact.

"14. The form—usually neglected—of the leading boundary of a passage, is also a definite quantity; in a sense, without constraint, it 'protects' the flow from external disturbing influences.

"15. The velocity of flow through the runner tends to vary as the radius. It cannot be arbitrarily treated as a constant.

"16. The width of flow is inversely as the velocity, hence also, inversely as the radius. This defines the form of the leading wall of the passage; it is hyperbolic if flow be confined to two dimensions.

"17. Since tendency to cavitation is removed, the use of shrouded runners to lessen internal leakage is not imperative.

"18. Non-uniformity of 'vortex action,' in an imperfect casing, at different portions of the circumference of the runner, gives rise to injurious reflex variations of flow in the runner as the angular position varies by rotation.

"19. Internal work, or slip, consequent upon the transmission of impulsion across flow, should be minimised. Therefore:—

"20. The width of the passages should be decreased, and the number correspondingly increased, until skin-friction imposes a limit.

"21. Skin-friction should obviously be reduced to the utmost.

"22. An arbitrary ratio, *i.e.*, 1 : 2, of diameter of eye and periphery of runner, is not necessarily efficient.

"23. Volume of discharge and velocity of approach in conjunction with angle, define the area, hence the diameter of the 'eye.'

"24. The ratio of the velocity of approach to that equivalent to the required head, defines the diameter of the 'eye' in reference to the diameter of the periphery. (This, in connection with 22, may afford a clue to the superiority, in the past, of the centrifugal pump upon low as compared with high lifts.)

"25. An inadmissibly high ratio (*vide* 24) denotes that recourse should be made to series working.

"26. The highest efficiency cannot be obtained under variations of discharge at constant head.

Mr. Smith. "27. But under certain conditions flow and head may be simultaneously varied in a certain ratio (fn : h.n^2), without necessary loss of efficiency.

"28. Discharge cannot be increased without increasing velocity.

"29. At a constant head, velocity beyond that necessary to attain that head is useless, but it must be produced, and purchased by the expenditure of energy in a rapidly increasing ration, if discharge is required beyond the designed volume.

"30. The excess kinetic energy cannot by any stationary system of guides, volute, &c., be caused to increase the volume of flow. It could be applied to increasing the head, but (*vide* 29) that is not required.

"31. Certain forms of curved vanes may form indifferent combinations of pump and turbine, utilising in part the excess velocity; but the consequent form will not be that of greatest intrinsic efficiency.

"32. Certain forms, required to work under very diverse conditions, may be the outcome of the preceding effect.

"33. Pending a radical departure in design, it seems that perfect, or high mechanical, or hydraulic efficiency, is inconsistent with departures, even relatively small, from constant conditions. Commercial efficiency is a matter distinct.

"34. The question of the other elements is foreign to the scope of the present paper, but in reference to the runner the deductions may be made that—

"(i.) As applied to more or less indiscriminate uses, existing forms may represent compromise intended to attain the least percentage of inefficiency by the application of the teaching of accumulated experience.

"(ii.) There does not appear to be any physical reason limiting approximation to theoretically perfect efficiency under suitable conditions."

Mr. Chester. J. N. Chester, M. Am. Soc. C. E., Pittsburg, Pa.—There are two viewpoints from which pumping machinery is looked at—that of the designer and builder, and that of the purchaser or owner and operator.

The speaker, having served a term on each side of the question, feels at liberty to discuss it from both points of view, but will confine himself largely to that of the owner and operator, since that of the designer and builder has been handled in such a masterly manner by Mr. Reynolds.

Dealing only as this paper does with large engines, having mentioned but one in Table 1 with a capacity of less than 10 000 000, and but four with a capacity of less than 15 000 000, there remains a wide field, along the same lines, in engines of smaller capacity and less horse power, in which field a very marked advance has been made in the last decade. But in this class, like the one mainly

touched on by Mr. Reynolds, no one or two features may be cited to which the marked improvement of a class of machinery in the field prior to that time is due, except in what is generally known as the low-duty triple, which virtually made its appearance at the Columbian Exposition in Chicago in 1903, and which now has a firm foothold, and will be treated of later in this discussion. Mr. Chester.

Duty.—As stated, there is no marked change in design that accounts for the betterment of this feature of pumping machinery, but we can attribute this increase in duty only to numerous small changes that have been made, such as the better location of valves; the reduction of clearances; increased expansion; prevention of thermal losses within the cylinder; lower terminal pressures; and, in general, better balanced machines and water ends designed to permit higher piston speeds, but to no one of these features can we attribute any marked advance. The speaker believes, however, that we are on the eve of a longer step forward in economy than has been produced by any one feature in the past decade, and that is the use of superheated steam, which will affect a substantial fuel saving without adding objectionable complications other than probably forcing the substitution of poppet valves for rotary or slide valves, especially on the cylinders where higher steam pressures are carried; and, while the increase in duty in the crank and fly-wheel engine with the minimum number of cylinders may not be as marked as shown in Table 2, where the performance of only direct-acting engines containing twice the number of cylinders has been tabulated, we shall expect from this source to realize results approaching these.

The speaker is surprised that Engine E 1205, No. 3, Table 2, credited with a duty of 174 735 801, has not been accorded a place in Table 1, but has been relegated to an annex used only as an illustration of a feature in economy, and further described as belonging to a species fast becoming extinct, for the results given would show in this regard, at least, a well-developed machine and one, in the speaker's opinion, that has its field.

From the operator's standpoint, most designers and builders have too little before them of all else but duty. To the operator this is never the prime feature, reliability must always come first, let that be produced or made up of whatever other features it may. A high duty is always desirable when not obtained through complexity, high first cost, and consequent large depreciation, and through other features that increase the cost of operating, other than the coal bill, and detract from the reliability of the machine.

The designation of pumping machinery as compound, triple expansion, or quadruple, according to the number of cylinders through which a certain quantity of steam must pass, is, in the

Mr. Chester. speaker's opinion, erroneous, and he thinks that a division based on a certain number of expansions would be more intelligent in all cases; for example, the so-called cross-compound has in the past been built for as high as twenty-one expansions, not, however, in pumping but in power engines; while the so-called low-duty triple seldom exceeds seven or eight expansions, the first certainly requiring a much higher steam pressure than the second. Notwithstanding this, builders have been known, within the last year (1904), to refuse to bid on a low-duty triple where less than 100 lb. of steam was available, but they unhesitatingly submit prices on a cross-compound with twice the number of expansions possible in the first type. On the other hand, engineers for purchasers have been known to reject bids for low-duty triple machines, on account, as they have said, of it being unsuitable, the steam pressure not being high enough. There is a difference between these two machines as regards steam pressure, but the triple machine will do good service on much less than 100 lb. of steam, and it is a much better machine to work under low pressures than most cross-compounds.

Would not a six-cylinder compound be a better name for the low-duty triple, and, in general, would not a so-many cylinder compound be a better name for any machine up to, say, sixteen expansions, and a so-many cylinder triple for any machine up to, say, twenty-one expansions, and a so-many cylinder quadruple for all machines above that number, until there is a demand for something beyond this; of course, basing all of the above on the average cut-off that might be expected in the high-pressure cylinder of the type of machine already christened?

In the field of engines with 5 000 000 capacity or less, with coal at $3 per ton or less, there are few instances where a more economical type than the low-duty triple would prove the best investment. From this field, in which the subject has been thoroughly gone into, this type of machine is driving out the cross-compound and other higher duty machines. In fact, there are fewer of the cross-compound machines installed each year, due mainly to the appearance in the field of the low-duty triple type, the former having the disadvantage of requiring, in the horizontal, a far larger number of wearing places, thus increasing the cost of maintenance by more complicated mechanism, requiring a more intelligent and, therefore, higher-priced attendant, and yielding under the best conditions a duty which is but a trifle higher, especially in the smaller units, and, which in many services, is exceeded by the low-duty triple, or as better christened, the six-cylinder compound.

Two comparisons that have come within the speaker's experience might prove interesting.

Bids were asked on a 6 000 000 engine for a Southern industrial

center. On the high-duty triple vertical, both crank and fly-wheel and direct-acting, the bids ranged from $80 000 to $83 000 erected. On the low-duty triple with reheaters, all cylinders and heads jacketed, the bids ranged from $28 500 to $30 000. In the latter case, the space occupied and, consequently, the pit was very much less, effecting a further saving in this respect, and as coal costs but $1.10 per ton in front of the boilers, the latter type was purchased. Mr. Chester.

At a Lake city in Wisconsin, there is a 4 000 000 vertical triple-crank and fly-wheel engine. Here coal costs twice as much as in the Southern city, the head is but one-third, and the cost of pumping, made up of fuel, pump-station employees' wages, oil, packing and waste, is approximately the same per million gallons. This does not mean, however, that the Lake city type would not do better in the Southern city, or the Southern city type less in the Lake city. The question is, would the Lake city type have proved a better investment in the Southern city?

At a Missouri mining center, the service is divided, the first being 90 lb. and the second, 40 lb. The first is performed by a low-duty triple engine of 3 000 000 capacity, which handles 2 500 000 per day at uniform speed. The second, by a cross-compound, crank and fly-wheel engine of 5 000 000 capacity, re-pumps this water, but works against the consumption, having a stand-pipe adjacent to the station as an equalizer. Its speed varies from the rate of 1 000 000 to 5 000 000 within the 24 hours. At both stations, the same coal is used, and for the week ending September 7th, 1904, the station duty of the low-duty triple was 51 500 000, and for the cross-compound it was 34 100 000, and the first engineer at this latter station is paid $20 less per month than the first engineer at the former.

In the purchase of an engine of the design to save coal, the other expenses are frequently run up far in excess of this saving, and while the practical use of the vertical-triple, high-duty design in large stations is not questioned, in the speaker's opinion, their use in smaller stations is too frequently not an economy.

Jacketing.—In the low-duty triple, or six-cylinder compound type, there will be a maximum gain from the use of superheated steam in the cylinders and reheaters, and in the jackets of the high and intermediate cylinders supplying the jackets of the low-pressure cylinders from the second receiver.

Pumps.—With a freer use of air-chambers on the direct-acting type, with capacities more nearly approaching those of the crank type, and, especially on the suction side, a greater speed will be practical, at least on severe services.

Auxiliaries.—Contrary to the opinions expressed in Mr. Reynolds' paper, the speaker favors the use of the surface condenser al-

Mr. Chester most to the entire exclusion of the jet type. The water supplies are narrowing down to two classes, ground or naturally filtered, and surface, which, to be pure, must be artificially filtered. With the ground-water supply we frequently cannot develop, and, where we can, cannot afford to develop, the supply to the extent of the extra amount required for jet condensers and, therefore, the use of a surface condenser, where the water pumped by the main engine may be utilized for circulating without additional cost, becomes more practical.

With a surface supply that must be filtered, it would be extravagance to filter an additional supply for the jet condensers of the high-service engines which are usually set at an elevation that would prevent an attached jet condenser from obtaining its injection from the raw water supply which is also frequently too turbid for practical use. This latter feature would also preclude the use of jet condensers in the low-service engines.

The surface condenser, while of greater first cost, is cheaper of operation, if well built, both as to repairs and power consumed.

In the speaker's experience as an operator and purchaser for operators, and an engineer in charge of operation, having purchased over thirty engines in the past five years, not a single case has presented itself where the jet condenser was considered more applicable than the surface type.

The driving of auxiliaries direct from the main engine to the exclusion of sufficient exhaust to heat the feed-water to 200° is not economy, and this generally dictates the use of independent auxiliaries in plants of less than 200 h. p.

Centrifugal Pumps.—This type has come to stay. Its field is at present limited, but will broaden. It is most at home where the water can flow by gravity to it. It will handle turbid and gritty waters under low heads at practically as low a fuel cost, with a less cost for installation and repairs, as most other types. These features are rapidly bringing it into the field as a low-service pump where the supply is to be filtered.

Gas Engines.—The field for the gas-engine pump, in the speaker's opinion, is practically limited to isolated plants of 500 000 or less or, say, 50 h. p., and is best adapted to higher service work where it becomes necessary to take from the mains or a high-level reservoir, and pump small quantities to supply suburban territories of a higher level than was ordinarily intended in the original construction of a works. This pump is absolutely unadapted to any but reservoir or tank service and presents greater complications, and consequently a higher cost of repairs, and, although the fuel consumption is ordinarily low, the low efficiency of the pump, the friction of necessary gears, etc., render it little more economical than a steam-driven machine representing the same investment.

The builder of pumping machinery should get before him the fact that 75% of the machines he designs or builds, which have a capacity of less than 6 000 000 in 24 hours, must work under a service varying from 20% of their maximum to full capacity within a 24-hour range, and that, in 50% of the cases, they must be capable of increasing the pressure in the discharge main 100%, and of accomplishing this increase with little difficulty; that reliable, accessible and economical machines, designed for such service, might differ from their standard patterns; and that the recent court decisions in New Jersey and Louisiana hold water companies responsible for total fire loss on account of the failure of the fire companies to extinguish fires. **Mr. Chester.**

Then again, in the United States, a fair average cost of supplying water in distributing mains, interest, depreciation and repairs taken into account in connection with fuel and other operating expenses, is probably three cents or thirty mills per 1 000 gal., while the cost of the fuel item alone seldom exceeds one cent or ten mills; and in the class of machinery discussed by Mr. Reynolds, five mills would be a fair average. We must also infer from the paper that pumping-engine builders generally are devoting their energies almost entirely to cutting down this amount by another half mill or so, and it is safe to say that for every mill cut off in general operation, the same amount is added to the other operating expenses. Would it not be well for them to pause in this search for better duty, and bend their energies toward clipping off a few mills at other points, where several are grouped within easy reach? When this is done, and the designer and builder of pumping machinery places reliability and simplicity ahead of duty, though not neglecting the latter, there will be fewer grey hairs in the heads of the operators.

Inaccessibility of Parts and Cost of Renewing.—In discussion of Mr. Hague's remarks, the speaker thinks that this feature in the design of pumping machinery has caused more grief to operators than all else in the make-up of pumping machinery, and were comparisons not odious, examples might be furnished where the expense incident to such features, considering the time that the engine is out of commission, will approach the annual fuel bill. Not infrequently has it come to the speaker's experience where, on account of a break in a part, the cost of which would not exceed $100, an expense of $600 to $700 must be incurred for removal and replacement, the machine being put out of commission for from three to four weeks.

The Gaskill engine was, in its day, a long step forward. To-day, by comparison, it is too short-coupled, not necessarily seriously complicated, but possessing a great many moving parts and awkward in its movements. It is a good machine on direct service, but, in

Mr. Chester. the speaker's opinion, is so nearly equaled by the more simple low-duty triple that there is little reason for its future manufacture.

The vertical cross-compound appears to be still popular, and a visit to the Chain of Rocks in St. Louis, Mo., would, the speaker thinks, give this machine a longer lease of life than has been predicted for it.

As to government of pumping machinery on reservoir service, little beyond the throttle, or ability to shift the cut-offs, is necessary, but in the large field of direct service there is, to the speaker's knowledge, no entirely satisfactory governor, and recent efforts on his part to synchronize, or to make work in parallel, direct-acting and crank and fly-wheel machinery, where the service is subject to quick and heavy drafts, have proven a failure, except by resort to the throttle. A device that will harmonize a Gaskill engine and a direct-acting machine on the above-described service will meet with a hearty welcome and a ready purchaser.

As regards greasing or lubricating of plungers, this is susceptible of abuse. The ordinary running engineer with ideas of economy starts out with the application of grease to his plungers, frequently to the extent of forming a tar coating productive of a great deal of friction, even to the extent, in the speaker's observation, of the frequent breaking of glands, to say nothing of the enormous increase in the fuel bill and general over-straining of the machine.

Plumbago, mixed with an oil of high viscosity, may in certain waters be used at times to advantage and for a reduction in friction, but frequently extreme acid or alkaline conditions of the water to be handled may even then provoke a tar or gummy formation on the plungers. On the whole, a good clean flax packing with the natural lubricating of the water has been found the most satisfactory.

Wear of Valves.—The wear of valves is proportionate to the velocity and the quantity and quality of water passing through them, and the adaptability of different valves to different waters has received too little study on the part of pump builders. There is a tendency to use a standard for too many different services, and in the handling of heavy pressures and gritty waters, such as are encountered in Western Pennsylvania, there is a broad field for the inventive genius, and a much greater annual saving might be effected than by clipping another mill per thousand gallons from the fuel expense.

Fire Engine vs. Water-Works Engine.—Since the water-works engine is, in many cases, especially on all direct-pressure systems, the fire engine (and where it is not, the fire engine must derive its supply from the delivery of the water-works engine), should it not be as well and better designed and built than the fire engine? Its

failure generally, if not always, causes greater consternation and loss than the breaking down of a fire engine. It cannot be spared to be hauled to the shop between fires, but must do domestic duty between times; nor does this argue for the material increase in the weight of the moving parts of the present popular designs, but the increase in strength of the material, the better distribution in the way of reinforcements, elimination of flat surfaces or square openings, the substitution of the strongest metals in many places for cast iron and more careful designs of connections, together with a more intelligent use of such adjustments as will form a more even discharge, less throbbing in the water column, and, in general, a less sensitive and quieter running machine than the present average. Mr. Chester.

High-Duty Tests vs. Operating Duty.—The speaker cannot agree that the general operating conditions do not differ greatly from those of the duty tests. Nine out of every ten specifications call for the duty test under maximum conditions of both quantity and pressure, which unfortunately are seldom the conditions under which the machine is to be generally operated. Besides this, operators cannot afford to hire trained experts as running engineers and still less can they afford to keep a number of assistant experts constantly stationed over the engine to keep everything in tune and at the highest pitch, in order that a few more millions of duty may be ground out; nor can they realize, throughout the year, duties which are obtainable in severe cold weather when the absorbing power of a circulating water enables the production of several inches more vacuum than the yearly average, to say nothing of the necessity of combating the steam and air leaks which every plant is heir to.

If the owners and builders of water-works could construct their works to fit the design of builders of pumping engines there would be less trouble, but they cannot do it; consequently builders generally should study more carefully the conditions to be met and design accordingly, rather than urge upon the oft dependent purchaser a certain design simply because they have the patterns, or that the design offered is their nearest standard.

In conclusion, the speaker believes that an additional table, similar to Tables 1 and 2 of Mr. Reynolds' paper, giving the performance of a like number of large engines, showing cost of repairs in proportion to investment, days in and out of service and station duty, would be of intense interest to owners and operators generally.

Charles A. Hague, M. Am. Soc. C. E., New York City.—In discussing Mr. Reynolds' paper the speaker will confine himself to the pumping engine for municipal water-works, as he has had most to do with that form. Although the paper is practically limited to ten years of retrospect, it may be of sufficient interest to go back of the decade seven or eight years, and mention that, as a matter of per- Mr. Hague.

Mr. Hague. sonal experience, he was present when the first three-plunger pumping engine was built for water-works purposes. Two of these were installed at Allegheny, Pa., in 1884, and in conjunction with Professor Greene, of the Troy Polytechnic Institute, representing the city, the speaker, representing the Edward P. Allis Company, builders of the machinery, tested those engines. The duty guaranty was 95 000 000 ft-lb. of work done by the water plungers, with a consumption of 1 000 lb. of dry steam; and that was thought to be a pretty high duty guaranty at the time, and rather difficult to meet; but, of course, successive steps have taken us very far above the 95 000 000-point for duty.

The speaker now has some work in charge, which involves a 15 000 000-gal., vertical, triple-expansion pumping engine of the kind which Mr. Reynolds describes as the leading type. This engine is being built by the Allis-Chalmers Company, and it is hoped that the present record for high duty will be broken by it. The water load is heavy, 120 lb. per sq. in.; the steam pressure from the new boilers will be 150 lb. at the engine throttle valve; and the speed of the pistons will be 225 ft. per min.; so that, as far as can be perceived, if the steam is in proper condition, ideal results ought to be obtained.

The pumping engine of to-day has come to be more or less a commercial problem. This does not mean that the commercial idea takes the place of the engineer's ideas, but rather that the engineer, at one end of the manufacturing establishment, has been forced, by the competition at the financial end, to throw his ideas into lines where expense of construction will be minimized, and where the utmost efficiency can be obtained for the least practicable capital investment. The capital account must be reduced, but reduced only by simplifying the design, and not by reducing the quality of the materials and workmanship. Not so many years ago, when the high-duty pumping engine was first brought out, it was necessary to go to special designers, not connected with manufacturers, and the work was laid out in very concise and complete plans and specifications upon which the various shops and works put in bids. The conditions were narrowed down so much that the poorer, less able, and less experienced shops were barred out, and the work naturally fell to the better class. But at that time the high cost of the pumping engine prohibited the introduction of the better types, to any general extent, for, to produce economy in manufacture, this class of machinery, like all others, depends upon the repetition of the same type. At the present time, the "commercial" has almost completely taken the place of the "special" pumping engine, by sheer force of repetition, and that which a few years ago was available only through special talent and occasional opportunity, is now

equaled and often excelled by the regular output of several establishments, each with enough business to keep a staff at work upon water-works pumping engines as a sort of commercial product. Mr. Hague.

The demand has been for a higher and higher class of pumping engine; and as the reduction of fuel expense became more and more an object, and there was a better understanding of the whole subject, the engineers and the men who pay the bills were brought closer together, until to-day, it is surprising to see what a high type of machine has been produced, for a price which in the past would have been considered simply ruinous. In the older days, the competition was between machinery at a low cost consuming a considerable quantity of steam and coal, and machinery at a high cost consuming a small quantity of steam and coal. This, of course, brought the fuel and capital accounts into antagonism, and in many cases the most economical line was worked out. In a great many cases, short-sighted people preferred to invest less in machinery and burn more coal as they went along, especially water companies which calculated that they could earn the coal in current service, but could not afford to put the capital into the engine all at once.

Mr. Reynolds refers to the test, by Professor Carpenter, of Cornell University, of a triple-expansion pumping engine of his own design, in the Milwaukee Water-Works, in which a duty of 154 000 000 ft-lb. was obtained. The speaker remembers distinctly when the test took place, and how much it was criticised, that many people thought there was a sharp trick played somewhere and that the figures were juggled. One of the engineering papers brought forward all sorts of arguments about steam pressure and piston speed, but the figures of the duty were correct, as was shown later by several repetitions of practically the same engine, the repetition being made possible by the facts that, to-day, shop practice and management have been brought to a state of perfection which brings the price of a high-class economical pumping engine down to a point which justifies the use of very high steam economy; and a much better engine can now be installed than most people would buy a few years ago, an engine in which is combined simplicity, high efficiency, great durability, and compactness. In fact, a very high type of pumping engine is now used in the comparatively smaller capacities, which, not long ago, were left to the field of low economy and low interest account.

Aside from the actual good qualities of a pumping engine, Table 1, which Mr. Reynolds gives, shows most emphatically that conditions and adjustments are the ruling causes of high efficiency. It will be seen in this table that the engine which holds the record for duty per 1 000 lb. of steam, No. 12, performed that duty with 126 lb. steam pressure, which, it may be remembered, some years ago, would

Mr. Hague. not have been considered fit to use in the triple-expansion engine. The speaker remembers when the Edward P. Allis Company built the first triple-expansion pumping engine, immediately after the construction of the Allegheny engines, in which the three plungers were introduced. The Allegheny engines were three-plunger, compound engines, with the middle cylinder the high pressure, and with the end cylinders both low pressure, the sum of the two low-pressure giving the proper ratio with the single high-pressure cylinder. The bed-plates were across the pump pit, with the pumps in the pit as at present; the shafts and wheels were supported overhead upon A-frames. But the very next step was this triple-expansion engine now being considered, which was put into service at the high-service pumping station of the Milwaukee Water-Works. In the case of the triple, however, the steam cylinders were placed overhead, in the marine style, and the shafts and wheels were supported by the bed-plates. That triple engine at Milwaukee was operated with 80 lb. steam pressure, and gave a duty of 129 000 000 ft-lb. Therefore, as may be seen, in proportion to the steam pressure, there has not been so very much improvement, even to-day, and the speaker's argument put forth at that time might still be considered a pretty good one, that cutting the indicator diagram into three parts, so as to reduce the range of temperature in any one cylinder, was fully as valuable as obtaining a greater number of expansions. The idea is to save what has already been secured by evaporation of water into steam, and save it to the utmost extent before going further; and when it is considered that the steam pressure has been doubled, and the duty only changed from 129 000 000 to 179 000 000, it might be fairly considered that there is something in the argument. It will require quite a good many repetitions under similar conditions, however, before new facts can be established.

In Table 1 in Mr. Reynolds' paper, the advocates of extremely high piston speed as an exclusive element of great economy are also confounded, when it is found that, in the engine holding the economy record for the highest 1 000-lb. steam duty, the piston speed was only 197 ft. per min.; and it is evident that a good deal of the uncertainty about piston speed is brought about by the fact that advocates of high speed do not look into the matter quite far enough. The speaker was for some years associated with the builders of the Worthington pumping engine, which is a slow-speed engine, and, under some conditions, that engine will hardly operate at all without steam jackets, which points out the fact that evidently steam jacketing and taking care of the expanding steam within the cylinder are more important than piston speed. The other extreme of the case is that when an engine is running too rapidly the jackets do not have time to act properly. So that, although this matter of

hurrying steam into a cylinder through very large ports, with the piston traveling rapidly, and then exhausting the steam quickly, looks at first glance as though it favored the life and durability of the steam, it will be perceived that there are other conditions to be considered, and one of them suggesting itself is the matter of clearance or waste room at the steam ports. Of course, high piston speed cannot be had without plenty of port area and plenty of room to get the steam in and out of the cylinder without undue friction. This matter of clearance is a very serious stumbling block in the way of high duty, as the speaker has most clearly demonstrated upon several occasions, where the evidence and results could not be doubted. Especially is small volume of clearances important in the low-pressure cylinder, where every cubic inch of steam unnecessarily sent to the condenser is so much loss; and, therefore, as against the argument of high piston speed itself, there must be considered the efficiency and conditions pertaining to the steam jacket, and also the matter of reduction of the clearance to the lowest practicable terms; both very important items indeed in the question of high duty. **Mr. Hague.**

The table also fails to substantiate the claims of the advocates of exclusively high steam pressure. It shows an engine operating with 200 lb. steam pressure per gauge, and although it gives the highest theoretical heat efficiency, it gives a less duty per 1 000 lb. of steam than others operating with a much lower steam pressure. The triple-expansion engine with 126 lb. steam pressure gives 16% better duty than the quadruple-expansion engine with 200 lb. of steam. This shows very convincingly that, after all, the conditions surrounding the test must be taken into consideration very carefully, and that any one of the items taken by itself cannot determine the general efficiency and fitness of the machine. Of course, when the water end of a pumping engine is considered, its attributes and demands will be found to vary greatly from those of the heat end of the machine. So it seems that there are a great many lessons and useful conclusions to be gleaned from this table, if it is looked at fairly and impartially, without too many hobbies.

Mr. Reynolds touches upon the matter of quadruple expansion, but it looks very much as though the reputation of that class of engine is yet to be made, and at some distance in the future, to say the least. It is rather doubtful, except under some special conditions, whether it will ever be adopted, and manufacturers and engineers will run some risk to their reputations in endeavoring to force it along faster than conditions justify. If quadruple-expansion pumping engines should be used, with four cylinders, it does not seem to be a step forward to use four plungers; indeed, quite the contrary. The delivery of water with four plungers is not

Mr. Hague. nearly as good as with three plungers, because the four points in the circle do not give as complete a blend of the deliveries, from the plungers into the regular flow, as do three points. One way to meet this objection would be to place the high-pressure cylinder immediately above the first intermediate, and then carry out the same general type of machine as in the triple, with special reference to the plungers. But when the thermal limits are considered, and also the fact that latent heat is put into the steam and then thrown away, to a very great extent, it shows that the problem is confined to a particularly narrow lane, and the speaker is very doubtful whether the triple-expansion cannot attain a ratio of expansion high enough to exhaust all the practical possibilities in the case.

The question of mechanical efficiency is another point which sometimes defeats carefully thought out plans. Mechanical efficiency is extremely important where the very highest results are sought, and anything short of 90% will be a serious obstacle to ambition in this line. The direct-acting pumping engine, like the Worthington type, with a very small item of friction and few moving parts, long ago took the lead in mechanical efficiency, going up as high as 94 and 96 per cent. In these engines, there was nothing to do but move the pistons and plungers, and the machine was controlled so automatically by the water column that little resistance was offered to the net work to be done. In the earliest stages of the vertical, triple, fly-wheel engine of which Mr. Reynolds' paper treats, the mechanical efficiency was about 85%, but, as the machine was perfected and certain objectionable points were eliminated, it gradually crept up to 93 and 94 per cent. The large Boston engine of the Allis type, probably designed by Mr. Reynolds, indicated a mechanical efficiency of 96 per cent. In fact, the vertical, triple engine, properly proportioned, with a fairly long stroke, will give no doubt as great a mechanical efficiency as any other type of pumping engine at present known.

Aside from the vertical, triple, fly-wheel type, Mr. Reynolds touches upon the direct, pumping engine, or the Worthington type, and as far as the views of the speaker go, in municipal pumping engines, there are really only three types of consequence: The Worthington high-duty engine of to-day; the Holly-Gaskill engine; and the Reynolds vertical type. Most pump manufacturers have followed one or all of these three types, as they are the leaders. Some cross-compound pumping engines are built, but they can hardly be called a type, only a modification, designed mostly for the purpose of reducing the cost and price of the municipal, commercial, pumping engine. They are built both vertical and horizontal. Personally, the speaker considers the vertical cross-compound to be a mongrel, and an evidence of bad engineering, principally for the

reason that the engine is so badly out of balance naturally, and needs to be put into balance by gross violations both in construction and operation. The single-beam engine with one bucket plunger would no doubt do better work. Or, if the choice is to be a compound vertical engine, the Leavitt type of pumping engine, in which there are two plungers (two bucket plungers, or two differential plungers), at opposite ends of a rocking beam, and one crank or one pair of cranks, would probably be the best line to follow. For direct service, with a system of closed pipes without storage or relief beyond a stand-pipe, this type would not answer very well, if at all; whereas in reservoir work, in which the distribution is independent of the force main, it would answer very well, but, if properly built, it would cost about as much as the triple vertical. Mr. Hague.

The Holly-Gaskill pumping engine, referred to above, in general design and under good construction, is probably one of the best machines ever brought out for direct service and closed circuits of pipes, in the absence of storage. It is made with two high-pressure and two low-pressure cylinders, one of each at each side of the engine, the machine being built only in the horizontal form. Each side may be operated separately in case of need, although this is seldom necessary, but, as an entire machine and on direct service, the Holly-Gaskill is a very good pump. It was built originally as a compound only, but of late years it has been made triple by adding one cylinder at each side of the engine, making a six-cylinder engine, much, in the speaker's opinion, to the detriment of the machine as a whole, as, on direct service for water-works, triple expansion, with the low points and peaks in the load, is much in the same condition as the triple-power engine would be for electric railroad work without a storage battery. This Holly-Gaskill type is now rather going out of existence, at least, in the large sizes, because the cost of the vertical, triple, three-plunger engine is coming down to a figure at which almost anybody can reach it for almost any capacity, coupled with the fact that distribution systems are growing to such an extent that, with properly proportioned units, the higher grade in economy can be utilized without crippling the best work of the triple engine to a prohibitive extent.

The horizontal, triple, pumping engine is also referred to in Mr. Reynolds' paper, but this machine is known very little in water-works service as a fly-wheel machine with three cylinders. Very little has been done with it, so far, excepting for elevator service, and for that service the three-plunger feature is probably as valuable as the gain in steam economy; but, of course, elevator service is not within the scope of this discussion.

The horizontal, six-cylinder, pumping engine of the Worthington type, has been repeated many times in the "low-duty" class, but

Mr. Hague. not with an engine of large capacity, although the Worthington high-duty engine, fitted with compensator cylinders, has been produced a moderate number of times in large, triple, water-works engines of the vertical class, and a few times in the horizontal class. The key to the situation in high-duty pumping engines is found in the item of fuel consumption. With coal at \$2 to \$4 per ton, and the fuel account forming from 40 to 60% of the total cost of pumping water for municipal supply, high-duty engines will often earn, in coal saved, the interest upon their entire cost, to say nothing of the interest upon the mere difference in cost between high and low duty.

In referring to points of construction, Mr. Reynolds mentions facilities for removing the larger parts, but such provisions are rather far fetched. In a long experience, the speaker has not seen many engines where it was necessary to take out the larger parts, especially on the vertical triples; and indeed the percentage is small, considering all classes of the regular makes of machinery. Of course, breakdowns will happen occasionally, but with an engine properly designed and built, it does not seem to be worth while to spend very much money to take care of the possibilities of breakdowns which very seldom occur.

The Corliss type of steam valve gear has been most favored for the past ten or twenty years, although there have been some other types used—some of them very good. Where steam pressures will allow it, and where a drop cut-off of the Corliss type is used, that arrangement of valve gear is hard to excel. The only objection that can be made to the Corliss valves is in the clearance, and this brings to mind the fact that soon after the triple engine was brought out by the Allis Company, they also brought out the cross-compound pumping engine, erected in the Hannibal, Mo., Water-Works, and the speaker at that time ascertained the conditions and made the arrangements for the contract for furnishing that engine. At about that time was introduced the practice of placing the valves across the cylinder heads, with the view of reducing the clearances, and the Hannibal engine was the first compound arranged and fitted in this way, with reference to valve ports and valves. This engine was a vertical cross-compound, having high- and low- pressure cylinders, mounted upon entablatures at the tops of the frames, and two vertical, outside-packed, plunger pumps below and in line with the steam cylinders. A triangular working beam had its ends connected to the plungers by links, and the apex carried the inner end of the horizontal connecting rod, this rod leading off and driving a double crank at the end of the machine, two overhanging fly-wheels being mounted upon the main shaft, one at each end. This was a very good type of engine. Its mechanical efficiency was high, and

it broke the record for compounds, in what might be called the commercial class, the duty going up to 118 000 000 ft-lb. per 1 000 lb. of dry steam. When the report was sent in, the results were looked at with some doubt by Mr. Edwin Reynolds, the Superintendent for the builders, and, apparently, he thought there had been some sharp practice. But, as a matter of fact, the reduced clearance in the steam cylinders, no doubt, cut a very important figure in the matter of high economy, and the duty then obtained was the high-water mark for compound engines for a long time thereafter. With the comparatively low speed of 180 ft., and with the areas and lengths of steam ports actually brought down to the real requirements, of course, a large portion of the waste room could be cut out. This Hannibal engine, apparently, on the first returns, gave 104% efficiency, which, of course, is known to be absurd; that is, the pump horse power was 4% higher than the steam horse power, but that is explained by the fact that the steam valves, across the heads, made such long crooked passages for the steam to and from the indicators that the indicators could not receive the full effects of the steam working in the cylinders, nevertheless, it was rather startling to figure up 104% efficiency at the first glance. Mr. Hague.

This matter of clearance or waste room at the cylinder ends is carried to a very exacting limit now-a-days. In preparing specifications for pumping machinery, in the regular course of business, the speaker simply endeavors to lay down the conditions very closely and very concisely, and then get the buyer into the very best hands to carry out the contract. The day for designing water-works pumping engines, outside of manufacturing concerns, has gone by; at present there are too many well-trained and bright people, and specialists at the work continually, where, not so many years ago, a high type of machine meant a special and independent designer, with a competition of builders. Without specifying, except in the very broadest terms, any particular type of machinery, and, in this matter of cylinder clearance, stipulating only the proportionate amount allowable, the statement would appear as follows:

Clearance in high-pressure cylinder, each end, 1.4 per cent.
" " intermediate " " " 0.6 " "
" " low-pressure " " " 0.5 " "

In one of the latest Boston engines, the clearance in the low-pressure cylinder goes as low as 0.45% (0.0045), a condition made possible by the use of poppet valves in the cylinder heads, which close even with the internal surfaces of the heads and leave no corners or ports. In some work which the speaker now has in charge, there is a regular Corliss outfit of steam-distribution valves on the high-pressure cylinder; Corliss induction valves and poppet exhaust

Mr. Hague. valves on the intermediate cylinder; and all poppet valves on the low-pressure cylinder. Of course, outside of the high pressure, the cut-off valves are operated from fixed points, leaving the high-pressure as the only one with automatic regulation, and that mostly to prevent the engine from exceeding a certain limit for full speed.

Mr. Reynolds refers to regulators, but it is hardly worth while to go into that subject. The fly-ball type of regulator is used, as a rule, principally to control the engine in its upper register of speeds, the action of the regulator being modified more or less by a spring balance, and arranged so as to fix the top limit of speed. In most cases, the water column makes a very good regulator, and also, to a certain extent, an addition to the balance wheel on fly-wheel engines. The engine cannot get very far away from the water column, and if the draft upon the pipes is increased, even with a fixed cut-off on the steam valves, the engine will automatically hurry up to meet the demand, and the increased speed will be seen at once. With a fixed cut-off, of course, the indicator diagram will remain the same at the increased speed, within the limits of the ports and cut-off mechanism; and, with the same mean effective steam pressure in the cylinders, the increased speed will give a proportionate increase of power, just enough to meet the demands of the increased flow of water. In a pumping engine, the elements making up the power act in a peculiar manner, and entirely different from a regular power engine. Under proper conditions, with a water system, the static head differs very little from the working head, and, consequently, the normal speed of the engine, with its static and friction load, produces a certain power, the only difference in the water pressure between "all on" and "all off" being the friction in the flowing water, and this should be as little as possible. Therefore, the speed of the engine and the quantity of water vary together, and the same diagram practically produces different powers, whereas, with power engines, the power and the diagram vary greatly, while the speed remains practically constant. Thus, with a reservoir load, the regulator is of very little use, except to prevent possible racing and to limit the top speed; and, even upon direct service with a closed circuit, the attempt to regulate pumping engines by special devices is very often money thrown away, and sometimes worse results are obtained than by limiting the top speed and leaving the engine to itself.

The steam jacket is a very important factor in the operation of pumping engines, although it might be considered in the light of a necessary nuisance. It is often the source of a good deal of trouble and care in obtaining the proper results, and at first it seemed as though it could not be gotten along with; but it has become familiar now, and the appliances are such that the jacket can be handled

readily and easily. In the Allegheny test, already referred to, during the second 12 hours of the run, the test being for 24 hours, the duty was running about 107 000 000 ft-lb., when, within an hour, it dropped to about 99 000 000 ft-lb., and, although the cause of the trouble was known, practically, the loss was allowed to go on, with the efficiency losing ground, until finally the fear was aroused that the duty would fall below the contract requirements, when the trap valve was opened and the jacket traps blown out; within another hour, the duty had risen to more than 108 000 000 ft-lb., showing most conclusively that the condensed steam lodged in the cylinder jacket was absorbing the heat from the expanding steam within the cylinder instead of reinforcing the working fluid, as intended. The evaporation was plainly shown upon the indicator diagrams. **Mr. Hague.**

The next item referred to by Mr. Reynolds concerns the plungers, and it is well known how important they are to the machine. The kind of plunger with which he is most familiar, and which is especially adapted to the type of engine most referred to, is the single-acting, outside-packed plunger, and this, without doubt, is a very satisfactory form, although, among engineers and water-works people, the wear and tear of the inside-ring plunger has been greatly magnified beyond what will actually take place under ordinary good conditions in other than extremely sandy water. There are horizontal Worthington engines which have been in service from five to ten years, pumping water in which there were finely divided alluvial and vegetable matters, the plungers working through solid metal rings, the rings being grooved at certain intervals throughout their lengths, and the length of the rings being about half the stroke of the engine; such plungers show a surprisingly small amount of leakage after six years of service. With grooved rings, even if the plunger should fit loosely, the change of velocity of the water, alternately meeting with the annular space and a groove, seems to defeat, to a great extent, its efforts to get past the plunger; such efforts being also retarded by the fact that the plunger is always moving in a direction opposite to that in which the water is endeavoring to leak. In some early experiences with steam fire engines, the speaker remembers that with a solid, smooth sleeve, and with a solid plunger, in the surface of which grooves were cut around the circumference, water could be readily raised 22 ft. by suction, starting with an empty pump and suction pipe. The plungers were made $\frac{1}{32}$ in. slack in the sleeve or ring. So that, outside of conditions where sand and other foreign substances absolutely damage the plunger or ring, the ring pump does very well; and with any kind of outside-packed plunger, the careless operator, by neglecting his packing or stuffing boxes, will suceed in wasting a great deal more water than a good ring pump will under fairly good conditions. A good plan,

Mr. Hague. for muddy and sandy water, with outside-packed plungers, is to pack very tightly and then grease the plungers; this means that if the leakage carrying the cutting material is prevented, and the friction of the tight packing is reduced by appropriate lubrication, very satisfactory results may be obtained, even in gritty water.

With reference to pump valves, there is very little to be said; the matter of valves has been reduced to a conservative basis, and compositions, into which rubber largely enters, are made up into pump valves to suit nearly all waters and pressures. A comparatively new form of pump valve was brought out about five years ago. It consists of a circular plate of steel or brass, not thicker than $\frac{1}{16}$ in. at the most, corrugated to provide sufficient resistance to the pressure, and with the outer edge of the valve and the inner edge, around the stem, reinforced by rings of hard rubber or soft metal for the bearing upon the valve seat, thus leaving the bars, radiating from the center to the outer ring of the seat, free from bearing on the valve. The result is that a positive shut-off is provided, both at the inner ring about the stem and at the outer limits of the seat, the real load of the water pressure being sustained by the metal plate, and thus avoiding the cutting of the body of the valve by the radial ribs of the seat. The pump-valve seats are generally screwed, or forced in upon a taper, into the valve decks of the water chambers, or are located upon the sides and tops of cages or turrets which in turn are secured to the valve decks. These cages, used mostly in the type of engine represented by Mr. Reynolds, were born of the necessity of avoiding troubles which overtook a set of Cornish valves and seats of brass which were placed in the water chambers of the Allegheny pumps already referred to, and the substitution acted so effectually that the plan was adopted as a permanent improvement.

With reference to independent auxiliaries, the speaker does not believe in unattached auxiliaries for pumping engines, where by any possibility they can be dispensed with and the member driven directly by attachment to the main engine. Of course, there are exceptions to this rule, as to all rules, but the attached air-pump, or feed-pump, or air-compressor for keeping the air-chambers charged, is preferable and perfectly possible at the moderate speeds at which pumping engines of the better class are operated. When all the steam pipes, steam cylinders, etc., are clothed and covered, as in the best modern practice, it is necessary to put heating apparatus into the engine-room for the comfort of the attendants; but the steam engine is a heat engine, and economy in the handling of the steam is what is sought chiefly, so that it would seem to be much better practice to provide by positive means about as much artificial heat as may be needed for comfort, through the medium of radiators, rather than by the waste of very much more heat than need be allowed to

escape. Wherever, from unusually high speed, the attached auxiliary cannot be used, of course, the independent apparatus is necessary, but this state of things generally argues conditions which have been badly met. Mr. Hague.

On the question of condensers, the speaker agrees with Mr. Reynolds upon the point that, outside of special conditions, not frequent in practice, the jet condenser is by all means to be preferred. The surface condenser is the more complicated, and the tubes will leak at times; under ordinary water-works conditions, there is no good sound reason why the surface condenser should be used, and, generally, a better vacuum can be mantained, with equal temperatures of air-pump discharge and consumption of energy or heat, with the jet condenser. In high service, so-called, where some of the water is pumped to a higher level than the general supply, and where the water represents a cash value of from $30 to $60, then the use of a surface condenser is justified, and the water in passing to or from the main pumps is generally sent through a surface condenser, thus providing a cooling medium for the condensation of the exhaust steam. That was the case with the first triple built in Milwaukee. There, also, was demonstrated the danger of putting back into the boiler without purification, the condensed steam charged with cylinder oil, although, as water, it seemed to be purity itself. The oil baked into a sort of gum upon the fire-plates of the boiler, and caused the plates to bulge and blister to a dangerous extent.

From time to time, the question of piston and plunger speed has been productive of a great deal of what has seemed to the speaker useless argument. In the first place, the speed has little to do with the general proportions of the pump proper, the area of the pump valves being a factor of the quantity of water to be moved, regardless of the speed of the plunger. A small plunger making a great many strokes per minute requires just as much valve area as a large plunger moving slowly; because if 1 000 000 gal. of water per 24 hours are to be moved, the openings must be in proportion to this quantity, or the speed of the water will create undue friction—mechanical friction of the machine—so that the only possible excuse for high speed is the steam end of the machine, and even at that, Table 1 in Mr. Reynolds' paper shows that high piston speed does not necessarily depend upon high steam efficiency. As long as the engine is properly steam jacketed, it can run at less than 200 ft. per min., and with the cylinders kept perfectly dry by the proper discharge of condensed steam from the jackets, the efficiency can be maintained easily at just as high a point as 1 000 ft. per minute, or even higher. In fact, the pumping engine of to-day, at say 187 ft. per min., shows as high an efficiency as any, and, in some cases at about this speed, higher than any other form of steam engine

Mr. Hague. known. The 30 000 000-gal. Boston pumping engine, with a high type of boiler, reduced the coal consumption to 1.04 lb. per horse-power hour; this is an engine making 17 rev. per min. and at 66-in. stroke, making 187 ft. per min. Thus it will be perceived that the question of speed, as far as the modern pumping engine is concerned, offers no excuse whatever for the attempts at handling such a stubborn element as water at a high velocity, with especial reference to reversal of column or current.

The speaker has a rough, although a very good, rule for valve areas, in connection with plunger speeds, and that is to divide the plunger speed by two, and let the result represent the percentage of the plunger area which the pump valves must have. This gives 50% for 100 ft. per min.; 75% for 150 ft. per min.; 100% for 200 ft. per min.; 150% for 300 ft. per min., and so on. This rule gives a velocity of 3.33 ft. per sec. through the valve gratings, as a constant for all speeds, which is about right for good practice and a long life for the machine.

The positively controlled pump valves have made very little or no headway in the United States, and it is hardly possible that the type of pump represented by such valves will ever amount to much in water-works matters. The fast-running pump, represented by positively operated valves, or any kind of a fast-running pump, for that matter, requires fully as strong a construction and fully as good workmanship as the slow-moving pump, and when to that is added the cost of the particular form of valves with their outside connections and the usual mechanism for handling them, there is at least as much money going into the pump. And if as much money is to be put into the pump for the sake of running it fast, with the conclusive evidence that slow piston speed at the other end of the machine holds the record for high efficiency, the speaker does not believe that fast speed is a very good engineering argument, or that it is a very good business argument. Of course, there are particular cases, but very few, where the fast idea might fit the better, but, in the main, the speaker does not advocate running so fast that it becomes necessary to handle the pump valves mechanically.

The wear of pump valves is practically proportional to the number of reversals per minute, and this is a very important point in connection with water-works engines; the idea leads up to the practice of limiting the number of revolutions, and then increasing the plunger speed by determining a proper length of stroke for the accomplishment of the particular purpose in view. Steam fire engines, under their peculiar conditions of service, may be operated at a very great number of revolutions—the speaker has run them up as high as 220 rev. per min.—but they are operated only a few hours at a time, and after the work and shocks are over, which is

Mr. Hague.

when the fire is out, the engine may be taken to the shop and completely looked over for possible derangement or damage. Therefore, a fire engine can be run at almost any speed, up to the point of running away from the water, during the continuance of a fire, and then taken to the shop and thoroughly overhauled for the next occasion of its use. With pumping engines, however, many of which work day and night for weeks or months without stopping, the conditions, as may be seen at a glance, are entirely different and much more exacting. The question of economy does not enter into the matter of fire engines, and it would be absurd to consider such a point with a fire raging and causing the loss of a sum which would be sufficient to buy up an entire fire department. But with waterworks pumps, where economy of operation and long life are the main points, the usefulness and desirability of high speed certainly disappear.

The speaker has noted what he considers at the present time as the ideal conditions for a pumping engine for municipal waterworks service for engines having a capacity of from 12 000 000 to 18 000 000 gal. per 24 hours, *viz.:*

Steam pressure	150	lb.
Travel of pistons per minute	225	ft.
Revolutions per minute	22½	
Length of stroke	60	in.

For engines having a capacity of from 20 000 000 to 30 000 000 gal. per 24 hours, as follows:

Steam pressure	150	lb.
Travel of pistons per minute	242	ft.
Revolutions per minute	22	
Length of stroke	66	in.

To standardize still further this class of machinery, the following table indicates what would be first-class practice, as to durability, economy, and general highest efficiency in water-works service, subject, of course, to adaptation to conditions, in the light of experience and environment in special cases:

All engines to run at a speed of 22½ rev. per min.
All engines to carry 150 lb. steam gauge pressure.
Velocity of water through pump-valve seats, 3.33 ft. per sec.

36-in.	stroke,	4 000 000	to	6 000 000	gal.	capacity	per	24	hr.
42- "	"	6 000 000	"	8 000 000	"	"	"	"	"
48- "	"	8 000 000	"	10 000 000	"	"	"	"	"
56- "	"	10 000 000	"	12 000 000	"	"	"	"	"
60- "	"	12 000 000	"	18 000 000	"	"	"	"	"
66- "	"	20 000 000	"	40 000 000	"	"	"	"	"

Mr. Hague. Considering the engineering details, the capital involved, the running expenses, and the actual economy in the operating conditions, wherever a plant can be put in with a unit or units large enough to cover these conditions, according to the speaker's observations during the past 20 years, the most satisfactory and constant service will be realized.

The conditions at Reading, Pa., seem to be very favorable for breaking the high-duty record, and, with slightly superheated steam, when the duty test takes place, there need be no surprise if the duty of 200 000 000 ft-lb. is approached still nearer than at present, if not actually reached. The conditions at Reading are as follows:

Capacity per 24 hr.	15 000 000	gal.
Steam pressure, per gauge	150	lb.
Total water load, per gauge	120	"
Revolutions per minute	22½	
Travel of pistons and plungers, per minute	225	ft.
Diameter of high-pressure cylinder	32	in.
" " intermediate-pressure cylinder	56	"
Diameter of low-pressure cylinder	84	"
" " water plungers	28¼	"
Stroke of all pistons and plungers	60	"

The Reading engine is of the vertical, triple, three-plunger type —the type which now holds the high-duty record of 179 454 250 ft-lb. per 1 000 lb. of dry saturated steam—and, if the addition of superheated steam will raise these figures, say 10%, which Mr. Reynolds admits as possible, what with the high class of workmanship expected, the refinement in possible adjustments of the steam distribution valves, the minimum clearances obtained in the design and construction, and the perfect steam-jacket system, the record figures of 197 399 675 ft-lb. duty may be reached, and then, by a very slight additional improvement, the 200 000 000 mark would be attained.

With reference to superheated steam for use in multi-expansion steam engines, the speaker has one general idea of the limits of usefulness, and that is to limit the superheating to a point that will just give a perfectly dry exhaust for the low-pressure cylinder; and if that point is passed, the result will be the sending of superheated steam to the condenser, which will mean taking extra heat in at one end of the machine and letting it out at the other end. The value of superheated steam, as a net gain in the use of pumping machinery, has not been demonstrated yet, and it is not exactly known just

what will be accomplished by it, although there is little room to doubt its usefulness to a reasonable degree. Those interested in the construction of superheating apparatus set forth the system to its fullest advantage of course, and perhaps some little allowances for different conditions have to be made; and further, there are some uses to which superheated steam may be put, aside from power generation, and sometimes the arguments may get slightly mixed, to say nothing of the great difference between plants of low and high efficiency, in exploiting the field of application of superheat to the best advantage. The speaker's idea is to superheat to the point that will pay the user and no further, and that point is certainly not known as yet, but it would be unreasonable to look for economy beyond from 10 to 15% in steam plants of high efficiency. Mr. Hague.

The particular means best adapted to obtaining the superheat in steam has not yet been investigated very thoroughly, and the cost of the superheat must be carefully looked into before the practical useful balance is struck. Liquefied air is extremely convenient and potent under some conditions, but it is costly to obtain; and before a balance of profit or loss is struck on the superheating of steam the consideration of how the superheating is to be accomplished must have its place in the problem. Will the superheating be done within the boiler setting, a part of the furnace, the uptake or some other part; or will it be done by an independent furnace? If it can be done within the boiler setting, perhaps too much heat is going to waste there. Perhaps another arrangement of the boiler, without superheating, will give so much better net results as to reduce greatly the apparent benefits of the superheating. Thus far the speaker favors an independent heating apparatus for superheating the working steam, as being much more manageable and as permitting the most and best to be made of the boiler upon its own merits, and then whatever actual gain may be obtained by injecting an abnormal quantity of heat into the steam can be counted and realized. After the steam has become just dry saturated and, therefore, a gas for the time being, the question of superheating involves the convection of heat by this temporary gas.

The question as to the effects of superheated steam upon steam valves is something about which very little is known as yet; although Mr. Reynolds practically claims that the amount of superheat which will pay will not hurt the Corliss type of steam valves at least, and the speaker agrees with him upon that point. If this freedom from injury really exists in superheated steam, it will be of advantage to use the Corliss valves upon the higher types of steam engines, because these valves are so completely amenable to automatic cut-off and regulation. Of course, the poppet form of steam distribution valve, simply rising from its seat and returning to it again without

Mr. Hague. sliding contact, has nothing to fear from any degree of superheated steam which it is practicable to maintain and utilize in a prime mover.

Mr. Reynolds has a paragraph on the different terms in which "duty" is expressed: the 1 000 lb. of steam basis, and the British thermal unit basis. It seems to the speaker that for the buyer of pumping machinery the 1 000 lb. of steam plan is the better, and that for the engine builder who wants to know just what he is doing, from the standpoint of the engineer and scientist, the British thermal unit plan would answer. The data usually supplied during a pumping-engine test are such that they will cover both plans, and it would not be inconvenient to state the case both ways when the results are reached.

With reference to criticism occasionally indulged in concerning high duties obtained on test, and the failure to reach these duties during regular service, there are generally plenty of factors to account for any such apparent discrepancies; and, as far as the speaker has observed, most disappointments generally arise from a failure to grasp completely the significance of the basis upon which the new engine is actually tested. Many of the higher types of pumping engines, without doubt, develop in regular service about as good economy of steam as when tested by the experts; indeed, with ordinary good care and the adjustments of steam-distribution gear possible in many pumping stations, there is no good reason for any great falling off in the actual steam consumption, and could not be without considerable abuse of the engines. The trouble is more apparent than real, and is caused by the fact that the actual boiler efficiency, with which the engine has absolutely nothing to do, cuts a very important figure in the every-day performance, and is rather prominent in the general records of the day. If a coal test is run with the boilers at the same time the engine is put through its contract test for duty, the boilers are operated at their best point of work, and the use of all extraneous steam, outside of the pumping engine being tested, is stopped. Afterward, when steam is used for several purposes other than running the engine, of course the coal charge is increased against the work shown to be done by the engine in every-day service. And further, the evaporation and general efficiency of the boilers under ordinary conditions are somewhat lower than in the tests; but there is little or no doubt that an engine, well-adjusted and in good condition, as well as in good hands, will change its steam consumption very little. Recently the speaker had two tests upon the same plant; in one, the analysis of the coal showed 13 966 heat units per pound, and another kind of coal showed 14 378 heat units per pound; in the first test, the boilers indicated 69% efficiency, and in the second test they indicated 73%

efficiency; thus, in the second test, the boilers indicated nearly 9% better results, while the steam consumption per unit of work did not change at all. Or, reversing the comparison, the first test indicated more than 8% worse results than the second test, as far as the boilers were concerned. Mr. Hague.

Therefore, the speaker draws a line between the engine and the boiler, holding that the engine is not responsible for the grates, coal, firemen, condition and efficiency of the boilers, etc.; and, upon the other hand, the boilers are not responsible for the leaks or undue loss of heat and steam by the engine. When a plant test is made, these facts have to be taken into consideration, so that it seems to the speaker that when a city buys a pumping engine, the steam test, as far as the engine itself is concerned, is all that the city is interested in, with reference to machinery. If the boiler conditions are not what they should be, that is not the fault of the engine, and the boilers should be examined to discover the deficiencies.

There is, also, a tendency for cities to buy larger pumping engines than immediate requirements warrant, and sometimes they stipulate rather higher water pressures than the plant is operating under at the time. This is often done from practical considerations, and often from the lack of proper consideration; the fact being lost sight of that a suitable determination of the size of the units will often be of great advantage in looking into the future. Of course, if a larger engine is bought than present needs demand, that will not bar the contractor from testing the machinery at its best point, and that is reasonable, of course; but, after the test is over, and the steam and water pressures are reduced considerably, the conditions for which the engine was designed are completely destroyed, and it is then unreasonable to expect in every-day service more than a good liberal percentage of the best results. The proper adaptation of units will help matters all around in pumping.

Mr. Reynolds mentions the possibility of reaching a higher point than the present record shows in the efficiency of a pumping engine, and, as far as the speaker can perceive, there can be attained probably just about 200 000 000 duty per 1 000 lb. of dry saturated steam consumed, that is, referred to the basis of dry saturated steam; but, practically, it may be necessary to use superheated steam to overcome the difficulties of radiation and condensation on the way to the goal. It seems to the speaker that with tight valves, proper load and steam pressure, and tight pistons with the minimum of friction, the 200 000 000 limit might be reached when the engine is carefully and closely adjusted. The No. 10 pumping engine in the St. Louis Water-Works now holds the high duty record, 179 454 250 ft-lb. per 1 000 lb. of dry saturated steam, and a good part of these high results on duty is due to careful management and close adjustment.

Mr. Hague. The engine was in the hands of experts of a very high class when tested, and when such an engine is brought down to an adjustment approaching in fineness the operation of a chronometer, of course the best results are likely to be obtained; and, with proper attention, the adjustments can be kept there, but then the expense and capital accounts come into the problem, and the question is raised as to how far it will pay to put money into close attention. Where coal is cheap, it may pay to buy a little more coal and get along with a little less attention. Just what part the superheating of the steam will play in obtaining the highest possible limits is as yet somewhat of an unknown quantity. The conditions under which superheat is used will be an important factor, as will be readily seen by noting that this engine, holding the record of 179 454 250 ft-lb., did not use superheated steam; while an engine in Table 2 with 154° fahr. superheat, and with a steam pressure, 18 lb. higher, only gave a duty of 174 735 801 ft-lb.

Mr. Reynolds touches upon the subject of turbo-centrifugal pumps, and in so doing opens up an extremely interesting subject to the engineer, although in water-works service this type of machinery has not yet won a place. Its actual efficiency, so far, has proven to be too low to meet the exacting demands of water-works people, who, thus far at least, find that it will pay a good deal better to keep up their capital account than to burn more fuel or use up more power in some shape or other. Within the past year (1904), the speaker has written a contract and specification for a turbine pumping engine for a large water-works plant, and upon the installation of the machinery very unsatisfactory results were obtained; the efficiency was found to be very far below a quite ordinary type of displacement pumping engine. The speaker believes that the efficiency will be improved, and steps are now being taken to improve it, but there has been enough shown to disclose the fact that turbo-centrifugal pumping machinery, as far as the pumping of water under heavy pressure is concerned, at the present time and condition, is far outside of the municipal pumping engine class. It is a pump of low first cost, and that is a very interesting point; and the speaker will go as far as to say that he hopes it will succeed, for the simple reason that it makes for economy of construction; and when there can be produced a turbine pump which will give high pressure, such as is needed in water-works, and regulate closely enough, especially for domestic service where there are no reservoirs, then it will take its place, provided of course that a current economy can be obtained high enough to justify the abandonment of the present general type of machinery. But as far as may be seen at present, it will be a better investment to pay three times the money for machinery and save from one-half to two-thirds of the

coal; because when the coal account is capitalized at from $2.50 to $3, or $4 per ton, it goes into money at an astonishing rate, and it will be found to be a great deal better business to put in the capital and cut down the coal bills. M. L. Holman, M. Am. Soc. C. E., told the speaker that when he was Water Commissioner of St. Louis, and put in the first high-duty pumping engine, he was criticised very severely, and was charged with buying coal outside of the city contract. The coal contractor found that the call for coal was so much less as to be very noticeable, and he had an idea that somebody must be running coal in the side door or the back window. But after investigation, it was found that the new pumping engine was not using the steam, and that was all there was to the matter. Mr. Hague.

It seems as though the driving medium of the turbine pump must be either electricity or the turbine steam engine, and thus far neither of these holds forth very great promises of sufficiently high efficiencies to counteract the discount in the delivery of the turbine pump; and unless that pump can be made to do from 25 to 30% better than it has accomplished yet, the displacement pump will hold its own in water-works service as now carried on, as far at least as the economical operation is concerned. But, aside from the actual steam or power economy of pumping, there are several practical questions, concerning the operation of the machinery in a satisfactory manner, regarding the delivery of the water into the system of pipes for distribution, or to the reservoir or stand-pipe. There has not yet been any demonstration of the ability of the turbine pump to meet water-works conditions. Under direct pressure, without stand-pipes, there is a serious doubt as to the successful operation of this type of machine, although, of course, no one knows what may be developed when a sufficient number of repetitions have been made to indicate where and what the difficulties are. Even with a stand-pipe, the turbine will be hard to control at the start, simply because what it will do under actual conditions is not known; thus far, upon a considerable scale, its first application resulted in the stand-pipe first being flooded, and then nearly going below the useful level, but, of course, these matters must be adjusted to the circumstances as additional knowledge of and remedies for difficulties accumulate. As now developed, the very wholesale manner in which the turbine handles the water is against it, and the fact that the plunger or displacement pumping engine works by increments which are easily increased or decreased in number to suit changing conditions of operation, renders its satisfactory control practicable. It seems easy with the turbine, with all the rush of its water constantly one way, to obtain regulation of flow by permitting it to work up to maximum head and minimum delivery, and then drop down to the low permissible pressure point and give full

Mr. Hague. delivery. This seems easy in the shop, by manipulating a valve to make the pump do these things; but in actual operation in a public water-works plant, with a long slug of water in a force main, and its velocity constantly changing, the performance takes on an entirely different phase. It is to be hoped that the manufacturers will persevere in their efforts until success comes, at least as far as the mechanical operation is concerned, then, if the economical test can be successfully met, that is, met so as to show the most water pumped for the least money expended, the turbine will command the field, and not before.

It is already adapted, and adopted, for the pumping of fluids which contain large quantities of solid matters, such as sewage, which would impede the operation of ordinary pump valves; and even for considerable quantities of comparatively clear water, for filtration-plant work, the centrifugal or the turbine is well adapted, principally for the reason that the high type displacement pumping engine with a very small useful load in proportion to the total work would fall off fatally in mechanical efficiency in proportion to the cost of the plant; whereas, with the turbine, even with an apparently low efficiency in elevating water, an economical steam unit of the small horse-power required in such low lifts would make a total performance in favor of the turbine plant.

In a brief summary, not following exactly the words of Mr. Reynolds, but echoing his idea, the views of the speaker are to the effect that from 10 to 15% of increased efficiency will still come to the displacement pumping engine; and, within the next decade, at least, this type of pumping machine will not be displaced by any radically different type of apparatus. In conclusion, it may be useful to note that engineering in the office and engineering in the field or engine-room are not exactly the same in appearance or results, the apparent difference between them being quite plain. This condition is quite natural, and most probably comes from the fact that in one case there is the office, or drafting-room man groping ahead, doing some pretty good reasoning and coming pretty near the mark; and then there is the other man, with the same knowledge as that possessed by the office man, but who, in addition, is right in the field and facing the various propositions in the act of application, and where he finds out some things which the inside man has not yet reached. And, therefore, if the results of this Congress can only be made to combine, as far as may be, these two sets of conditions, it seems to the speaker that great progress will surely be made; and when these papers and discussions are published, they may lead to valuable results.

Mr. Reynolds' paper, as will be seen by its opening paragraph, is written specially with a consideration of pumping engines for

municipal water-works service. It represents a great many years, twenty or more, of experience and responsibility, and some very careful observations by a very close observer. No matter what may be said about what will be done, the results given here represent what has been done and what has been paid for by cities and towns in all parts of the United States. Some of the machines have been bought under very exact scrutiny and under very strict specifications, and some of these high-type pumping engines have been sold under specifications wherein a bonus is paid if the duty called for is exceeded, and where a forfeit is exacted if the duty falls below that called for in the contract. There are very few firms who have the necessary courage to go into that kind of competition and bid at a ruinous price with a full confidence of winning their way out by the superior efficiency of the machinery. Some of the engines in Table 1 have been sold under these conditions, wherein, if the contract was simply let for a specified price and nothing else, there would have been a loss to the builders, but, on account of the bonus stipulated and earned, a profit has been made on the contract. Some of these contracts provided that the builder should be paid $500 per million for every million foot pounds developed in excess of the duty called for in the specifications, and that $500 should be forfeited and deducted from the settlement of the bill for each million foot pounds shortage. Mr. Hague.

The paper is based upon a very long and varied experience in the actual production of pumping engines which have been sold under the most skilful supervision possible for the buying cities to obtain. The larger cities of the country have some very able men in their engineering departments; any one doubting this should try to do business with them, when they will find out that these city engineers, superintendents and commissioners are exacting in their demands that the contract be fully met. The fact that a man is willing to depend upon the bonus he has in sight for his profit shows that he has considerable confidence in his machinery.

During this discussion, Mr. Chester mentions a pumping engine in which the repairs had been very excessive, so much so as to cause many grey hairs upon its owner's head. That engine was a very poor one, no matter who built it. Any pumping engine on which the repairs cost as much as he mentions has something radically wrong in its make-up, or in its adaptation to the conditions of the work to be done. It has been said that it is as much of a study to make an engine durable as to make it economical; in fact, that economy is all right, but does not come first. The speaker admits the necessity of staying qualities; and contends, further, that the first requisite of a pumping engine is to pump water, and to pump water continuously. It makes no difference what other things

Mr. Hague. it can do, if it fails to pump water it fails in its greatest mission. And he will also state that it has been as much of a study to make the better types of pumping engines pump water continuously as it has been to make them do anything else, and they do excellent continuous work, as well as give the high duties already noted. There are plenty of notable examples of the type of pumping engine represented by Mr. Reynolds, types of several regular builders in this line, and special types, that for years have pumped water successfully and continuously with nothing whatever abnormal in the repair account, in fact, some of them have had remarkably low repair accounts, and this, of course, suggests at once the idea that if any particular pumping engine is not adapted to its work, or if money enough was not paid for it to secure the proper machinery for the purpose in view, then the evidence of misapplication and incompetency will most assuredly appear; and it is a perfectly safe statement to make, that when a pumping engine shows such distress as Mr. Chester sets forth, "some one has blundered."

The turbo-centrifugal pump is touched upon lightly in Mr. Reynolds' paper because there is little known about the machine. Probably Mr. Reynolds knows as many facts about the turbine pump as most people. There is at least one good reason why this type of pump has yet to win its position in water-works pumping stations, and that is, as soon as a turbo-centrifugal pump is forced so as to bring it up in efficiency, the water and whatever it contains will be driven through a great many small passages at a very high velocity, and instead of it being a very durable machine on account of the absence of valves and other mechanism, it may be found that it will wear out very rapidly where there is even a small percentage of sand or grit in the water, and most waters have some sediment, although in many cases it is small in quantity. With the turbine, the higher the pressures against it, the faster it must run to meet the requirements, and it may be found that in the long run the turbine will require fully as much care and repairs as any other engine. But time will tell, and the turbo-centrifugal pump will certainly take its proper place in the field of usefulness at exactly that point in the scale for which its capabilities are best fitted. If it is the best, nothing can stop it, and if it is not the best, nothing can save it.

Mr. Fanning. J. T. Fanning, M. Am. Soc. C. E., Minneapolis, Minn.—Two matters have been made conspicuous in the discussion. Mr. Chester has referred to the decisions of two courts, which made water companies liable for damages by fires when there were shortages of water for fire purposes. When we consider the frailties of pumping engines, those decisions seem of exceeding great importance to water companies.

Mr. Hague mentioned the reference in Mr. Reynolds' paper to the necessity of properly proportioning the parts of the water ends of pumping engines and spoke also of the frailties of steam fire engines. Those court decisions will seem doubly important if, in addition to failures of pumped water supplies, there may possibly be a failure of a gravity supply to provide sufficient water for fire extinguishment. **Mr. Fanning.**

The speaker recalls a case where it was claimed that there was a failure of a gravity system, and where the claimants thought, for a time, that the failure was fully demonstrated. Sixteen years ago, there was a large fire in the wholesale district of one of our Northwestern cities, and an important warehouse with its contents was destroyed. Within one week, another large warehouse near-by was similarly destroyed. The Fire Department was criticized in each case and replied that the water supply was inadequate, and that the fire engines produced a vacuum in the water pipes which supplied water by gravity pressure. The Board of Water Commissioners believed that the water mains were adequate to supply the nine steam fire engines with water. They requested the speaker to investigate the capacity of the water mains, and his report stated that the mains were capable of supplying sufficient water for the nine steamers used on the two occasions mentioned. The static pressure at the hydrants was about 59 lb. per sq. in. and, as the water mains were of liberal size, it was estimated that there should remain 30 to 35 lb. water pressure while the nine fire engines were in operation. The Fire Department was not satisfied with that report, and an agreement was finally reached that a practical test should be made with the engines in the same positions as at the last of the two fires.

John W. Hill, M. Am. Soc. C. E., was requested to direct and to report on the test, and a date, several months later, was agreed upon. In the meantime, the fire engines went into the shop and were put in prime condition. Preparatory to the test, pressure gauges were attached to the water mains on the various lines of approach, and gauges were attached to the fire hydrants to which the fire steamers were to be connected.

When the time of the test came, the nine steam fire engines were placed in their former positions and ordered to continue in work four hours, throwing fifteen hose streams as before. Excellent fire streams came from the hose nozzles at the outset and so continued until the engines were ordered to be speeded up to full capacity, when again the streams began to be weak, as though the water supply were being exhausted. Thus it was again apparently demonstrated that the water supply had failed in the emergency. But the gauges on the water mains and on the hydrants did not indicate

Mr. Fanning. any tendency to vacuum. The speaker observed that when the fire engines were at their highest speeds of revolution and the hose streams weakest, the water pressure increased within the fire hydrants and rose above 35 lb. in some. Observations led clearly to the conclusion that the inefficient conditions of the hose streams were due to faulty actions of the fire-steamers' pumps, and not to lack of water supplied by the mains. To demonstrate the abundance of the water supply, the speaker caused a short line of hose to be attached temporarily to one of the hydrants in use by a steamer. From this line of hose, there came a direct-pressure stream equal in volume and force to the steamer stream from the same hydrant.

Thus was it practically proved that there had not been a failure of the water supply when three grand demonstrations had seemed to indicate such a failure as might have led to claims for damages by loss in two great fires. Thus, also, was emphasized Mr. Reynolds' suggestion that all the parts of the water ends of pumping engines should be properly proportioned, for here was a case in which the valves of the pumps were unable to admit water to the claimed capacity of the engine. The pump cylinders were but partially filled with water at each stroke, and so the faster the engines were worked above their actual capacity the less efficient were their hose streams, even when the pumps were supplied with water at 30 lb. per sq. in. pressure on the suction side.

Mr. Holman. M. L. Holman, M. Am. Soc. C. E., St. Louis, Mo.—The attainment of extraordinarily high duties with pumping engines is a matter which rests on a great many different factors, and largely on the final adjustment of the engine for the test. Of the twenty or twenty-one pumping engines mentioned by Mr. Reynolds, seven of them are in St. Louis, Mo., and the world's record is held by one of them. That engine was adjusted very carefully, and its excess duty over other engines simply means a better adjustment of the engine, a better mechanical efficiency, and a better setting of the engine for the work that was to be done. Engines may be built at the same time, from the same plans, and of the same dimensions, and yet a considerable difference will be found in their duty, and that difference is entirely in the adjusting of the engine. The speaker will say that for the engine which took the record, the low-pressure cylinders were jacketed, not with steam, but with hot water from the cylinders and from the steam traps, the hot water being at a temperature, of course, greater than the steam in the cylinders, and sufficient to do the work. So far as future increase of duty is concerned, we must look more toward mechanical excellence and mechanical perfection of the machine rather than to thermic efficiency. The superheating of steam cannot be carried higher than that which will give the proper condition of exhaust.

As Mr. Hague says, excessive superheat is simply throwing coal through the engine. The present thermic efficiencies of pumping engines are high; the mechanical efficiencies in some conditions can be bettered. Mr. Holman.

In mathematical investigations of movements of water, a writer should always keep clearly before a reader the total energy available and lost, *viz.:* kinetic energy; potential energy; and the losses due to friction. If this is done, a great many apparent discrepancies will disappear. This applies particularly to Mr. Venable's theoretical discussion.

G. O. M. OLSSON, ESQ., Stockholm, Sweden.—Having been for a number of years closely connected with the development of high-speed centrifugal pumps in connection with steam turbines, it is only natural that the speaker's attention should have been attracted by the reference, which Mr. Reynolds makes in his very ably written paper, to the performance of some De Laval centrifugal pumps that were recently tested by Professors Denton and Kent in the United States. The parallel, that Mr. Reynolds draws between the economy of these pumps and that of the best American pumping engines, is a comparison, which by no means does justice to the De Laval pumps. The speaker may mention, that the De Laval turbo-centrifugal pumps tested by Professors Denton and Kent developed only 60 to 80 h. p., whereas the American pumping engines, to which Mr. Reynolds makes reference, were of ten times or more that capacity. The table, that he gives us in the beginning of his paper, includes pumps ranging from 323 to 1 186 h. p. Mr. Olsson.

The centrifugal pump has received great attention during the last ten years. Before that time engineers did not know much about the efficiency of centrifugal pumps, because it was very difficult to ascertain how many horse powers were required to drive them. Now, since we have commenced to drive these pumps by electric motors, it is a very easy matter to get at the figures of efficiency. The development of the centrifugal pump on a larger scale is still unfinished, so we may reasonably expect still better results from it. At the present time, it is not claimed that the turbo-centrifugal pump shall compete with a high-class piston pump for continuous service in town water-works. But it is claimed that in special cases the turbo-centrifugal pump can show economical advantages above reciprocating pumps, and we have to take especially into consideration just what Mr. Chester has mentioned, that the cost of overhauling the machine sometimes cuts a very high figure in the running expenses. In this respect, of course, the turbine pump presents considerable advantages. The first cost of the centrifugal pump driven by a steam turbine is very low, which is especially desirable in the case of plants operating intermittently.

Mr. Olsson. The amount of money represented by rents and maintenance will in many cases more than balance the higher cost of fuel. The centrifugal pump, as applied to steam turbines, has an advantage over centrifugal pumps driven by steam engines, because it can be driven at a high speed, and consequently can be constructed with impeller wheels of very small diameter. That, of course, makes the passive resistance of the wheel running in water smaller than in the case of low-speed pumps of a larger diameter. This is the reason why the steam turbine builders have their eyes on the centrifugal pump as a means of widening the field for the practical application of the steam turbine.

The speaker finds it difficult to reconcile with one another some of the figures in Table 1 in Mr. Reynolds' paper.

The quadruple-expansion engine, No. 7, Nordberg Manufacturing Company, is represented as having shown a thermal efficiency of 22.8%, its steam consumption being 12.26 lb. per indicated horse power hour and its duty, 162 132 500 ft-lb. per 1 000 000 B. t. u.

The triple-expansion engine, No. 13, Edward P. Allis Company, is stated as having a thermal efficiency of 21.63%, although its steam consumption, as given, is only 10.33 lb. per indicated horse power hour and its duty 163 925 300 ft-lb. per 1 000 000 B. t. u., which is about 1% better than the Nordberg quadruple engine. There is a steam pressure of 15 lb. in favor of the latter engine, but this does not account for the discrepancy in Mr. Reynolds' figures.

Mr. Mueller. OTTO H. MUELLER, ESQ., Berlin, Germany.—The speaker desires to touch upon a very few points in Mr. Reynolds' paper in order to compare the statements made with the actual practice in Europe. On page 522, Mr. Reynolds says that

"American designers have never adopted the mechanically controlled valve nor the multi-ported ring valve common in European practice, but they have quite generally accepted rubber valves as satisfactorily fulfilling all the requirements of ordinary practice."

To this the speaker would say that although the so-called mechanically controlled valves have been built by quite a good many concerns in Germany, they have been almost entirely dropped in the last few years; and, to-day, only a very few engines are fitted with controlled pump valves. Most engines are built with the same small or multiple valves as used here; but owing to the higher pressures which we usually have on water-works engines, they are not often made of rubber, but almost in all cases of metal. At the same time, experience has shown that with properly-designed, automatic multiple valves, at least the same speed can be attained as with the controlled or mechanically operated valves. The speaker has in mind two engines, each of 12 000 000 gal. capacity, and pump-

ing against 225 ft., which have been installed recently in the Budapest Water-Works by a local firm. These engines are fitted with small metal valves, and they run up to 80 and 84 rev. per min. So that shows, that, if properly designed for an engine of that capacity, at least, a very high velocity or number of revolutions can be obtained with automatic valves. The speed through the valves of these particular engines is about 5½ ft. at about 80 rev. per min., which is in excess of the speed recommended in Mr. Reynolds' paper, which is 3½ ft. per sec. Mr. Mueller.

The speaker was surprised the other day, when he went to Chicago, to hear that several engines have been ordered for that city which will be supplied with mechanically operated valves.

The second point is the piston speed, or the speed of pumping engines, generally. Mr. Reynolds speaks exclusively of piston speed, giving the number of feet of piston travel per minute. At one point only he mentions that: "As the wear on the valve and on the engine in general is practically proportional to the number of reversals per minute, it follows that the renewals and repairs are greater on high-speed machines." Now, in the speaker's opinion, it would be clearer to point out that all the difficulties with engines generally, and especially with pumping engines, will be met with in the number of revolutions per minute. It is not the amount of piston travel that makes all the trouble, but it is the number of reversals of the piston in a given time, more or less. If we take a pumping engine that runs at 30 rev. per min., and we make it half stroke and run it at 60 rev. per min., we will find that the engine has the same piston speed, but that it will not work half as well if no other changes in the design are made. Much care has to be exercised in order to build pumping engines with a high number of revolutions per minute, if they are expected to run smoothly, especially the pump valves which have to be given a smaller lift.

In reference to superheated steam, the speaker finds that in general its economy is doubted in the United States, and that engineers here do not believe much in the economy of highly superheated steam. In Europe, we go higher in superheating than is usually the case here. The speaker knows of a pumping engine in the neighborhood of Berlin, which only works with about 200 h. p., and shows a duty of 170 000 000 on steam. He must, however, admit that on large engines, and, of course, on large pumping engines also, the difference is not so marked; because an engine of large horse power will be economical, even with saturated steam, and the difference with superheated steam will not be so large as on a smaller engine. Now in Europe, especially in pumping plants, we have very much smaller engines than are used in America, because we do not have to pump as large a quantity of water *per capita*, as

Mr. Mueller. they do, for instance, in Philadelphia, or St. Louis, or Chicago, and other large cities. We pump about one-fifth or one-sixth as much. Mr. Reynolds also mentions the Worthington engines in Chicago. He also gives a table which shows a very high duty for superheated steam, and at the same time he states:

"It would appear from the steady decrease in boiler efficiency with the increase in superheat, that in this case, at least, there was but little actual gain in commercial economy due to superheating.

"It would appear from the unofficial figures obtained during the regular operation of these engines that the duty on coal runs about 76 000 000 without superheaters and 84 000 000 with superheaters, indicating a gain of about 10% from the superheat."

Now this duty of engines operated regularly every day is much less than those shown at the test; and Mr. Reynolds gives the reasons for the discrepancy in the duties in ordinary service and those in tests. The speaker thinks that it would have been fair to mention that these reasons, mentioned on page 527, existed in the case of the Chicago engines. He says:

"Where the duty is based on coal there are many opportunities for loss, for while there is comparatively little difference in the efficiency of various types of boilers when operated under proper conditions, there may be a marked loss in efficiency when operated at much above or below the normal rating."

Now, the speaker happened to be in Chicago visiting the stations, and the superintendent took him around, and he saw that the head that the engines were working against was about 85 ft., which is only about 56% of the head at the duty trials, and he thinks that the difference in duty is easily accounted for by this. The engineer also told him that a similar proportion between the every-day duty and that obtained at the tests is shown by the fly-wheel engines at the other stations in Chicago.

The speaker infers that Mr. Reynolds is not much in favor of direct-acting engines, but he cannot quite see why a direct-acting engine should not give at least the same results as a fly-wheel engine. By means of compensating devices, the number of expansions can be run as far as with a fly-wheel engine. The clearances in the cylinders can be kept down also as low as in crank and fly-wheel engines; and as to the mechanical efficiency of a direct-acting engine, there is no doubt that it should be even a little higher than that of the crank and fly-wheel engine; and last, but not least, the speaker believes that the efficiency of steam jackets in the direct-acting engine must be higher than in a fly-wheel engine, due to the pauses between the strokes where there is extra time given to the steam jackets to act upon the cylinders.

The speaker would like to complete the information given by

Mr. Olsson about centrifugal pumps, by some personal experience which he has had in the last six or eight months. He was called upon to test some centrifugal pumps manufactured by a firm in Leipsic. The testing was done by means of a dynamometer and a weir. Previous to this the speaker had tried to test these pumps in the mines where they had been installed, but found that no degree of accuracy could be secured on account of the poor means for measuring the water and power; the efficiency of the electric motors was never known, or very seldom, and then not accurately. Tests of the pumps right in the shops where they were built, by means of a dynamometer which had been calibrated before were therefore preferred. Now, these pumps were not very large; the largest developed about 30 h. p. and the largest quantity of water pumped was about 1 500 gal. per min., against about 120 ft.; while on the smaller pumps it was about 20 gal. per min., against about 400 ft. head. The pumps were single stage, and two and three stage pumps. The mechanical efficiencies which were found on the normal load of the pump, or normal capacity at normal head, varied between 72 and 79%; and the speaker thinks that a result of 79% efficiency on a pump developing about 30 h. p. is quite remarkable, and that on pumps of large capacities, a much better efficiency might be expected. It is remarkable that the efficiency of such a turbine pump is not decreased by the number of stages. You will find that a pump of four stages, for instance, will have a better efficiency than a single-stage pump; that is, if you take the four impellers of a four-stage pump and test each separately under the head that it has to overcome and all for the same quantity, you will find the four stages give a slightly better efficiency than each single stage; because of the four impellers in the four-stage pump, three work under pressure on both sides, and only one under suction lift on one side, this one being that showing the least efficiency. It has further been stated, which seems very natural, that the higher the speed of a turbine pump, the better the efficiency. On a higher speed, the impellers will be smaller in diameter, offering less friction surface to the water passing through, and their friction will naturally be decreased. The same pump will be cheaper of course, and the motor power of the pump will also be cheaper; and from what the speaker has seen, it seems that there are more difficulties at present in the way of making a fast-running electric motor than in making a fast-running turbine pump. Now, it is very hard to say what the field will be, which the centrifugal pump will cover in the future. It seems that the turbine pump for smaller quantities, for high speed and high head, is not the best pump for a gritty or dirty water, because when you come to that high speed, the openings in the impellers will be very narrow, and if you should design such a small Mr. Mueller.

Mr. Mueller. propeller with an opening about $\frac{3}{8}$ or $\frac{1}{4}$ in. in width, and all the vanes in between, and the vanes in the diffuser, you will find that this is at least as great an obstruction to the water as a pump valve with all its ribs, etc. If anything sticks in the impeller, the efficiency of the pump will be greatly reduced, and we must be careful to protect these pumps efficiently against material which is likely to stick in the vanes. To remove it, the whole pump has to be taken in pieces. At present the centrifugal pump combined with a steam turbine, and the steam turbine supplied with a condenser, the whole for, say, 100 h. p., would be very much more expensive than any reciprocating steam pumping engine with which it can be compared. Therefore, steam-pumping plants with centrifugal pumps offer no advantage in first cost. Besides this, we must consider that the steam turbine has only been developed for large sizes, and the economy of steam turbines in medium sizes, say, 50, or 80, or 100 h. p., as used every day in factories, pumping plants, or other pumping stations, is not generally known. A possible future field for the turbine pump is the hydraulic—that is where high pressures are used in operating cranes, presses, or elevators; because the pump forms a safety valve in itself, and the whole installation seems to be very simple if compared with a reciprocating steam pump, for instance, which is regularly fitted with all possible kinds of governors and safety devices, requiring care and giving difficulty in stopping and starting, with its condensation of steam in the cylinders, etc. These steam pumping plants are not at all economical. Therefore, it seems that there are more advantages with the turbine pump for operating a hydraulic plant than with a steam plant.

Mr. Venable. WILLIAM MAYO VENABLE, ASSOC. M. AM. SOC. C. E., New York City. (By letter.)—The writer invented the name "Velocity Pump" to describe a general kind of pump of which there are many types. Although all velocity pumps in actual use are of some rotary type, Equations I to XIV, with the exception of Equation II, apply to any other type that might possibly be devised. It was, therefore, injudicious to introduce Formula II so early in the paper, as Mr. Harris, and doubtless others, have been misled to believe that subsequent formulas are limited by Formula II, although that is not stated in the text.

Figs. 1 and 2 are velocity diagrams, and no line in either figure represents any section of a runner. The angle, β, is defined in the paper, not with reference to the vane, as supposed by Mr. Harris, but with reference to the axis of the "infinitesimal stream." This makes it possible to apply the formulas to streamlets not in contact with the vane, if their actual paths can be discovered, by a study of the distribution of the flow between the vanes.

The paragraph on page 474, regarding pressure head produced

within the runner must be understood to refer, not to the difference in head between different particles differently situated at the same time, but to the increase in pressure at the same particle at different times. Thus when there is no flow through the pump, each particle will have no motion with reference to the adjacent runner, and will not be undergoing any change of pressure, however rapidly it may be moving with reference to the casing, or to other things, or however great its actual pressure head. What Mr. Harris states is certainly true, that when the pump is not discharging the pressure will be greater, as we consider it at different points from the center out. In that case, we are not producing pressure, but merely maintaining pressure already produced. Mr. Venable.

Perhaps the paragraph referred to would have been clearer if it had stated that the runner serves to produce velocity head and pressure head, the latter as stated in the paragraph as written; but this meaning was intended in the paragraph immediately preceding. Equations III, IV and V should make this matter clear; and the writer does not understand how Equation III can be a misapplication of Bernoulli's theorem under the ideal conditions assumed.

"Centrifugal" pumps are defined in the paper according to structure, because all other definitions with which the writer is familiar rule from the class many pumps that are ordinarily called centrifugal. Were it possible to limit the term "centrifugal" to the truly centrifugal types, he would be very glad to do so.

Whether Fig. 9 is absurd or not for high lift pumps depends upon the proportion of the quantity to be handled to the head, and not upon the head alone. It is true that the writer personally has had more experience with pumps of very large capacity and moderate lift than with those of small capacity and high lift. The diagrams in the paper are intended to illustrate the principles involved, and not to suggest the design necessary to meet any particular condition.

Pulsation is an evil, but an unavoidable one, and not necessarily an evidence of bad design, for there must be unequal distribution of the flow between the vanes because the motion is communicated by a moving surface. We may make the pulsations very numerous and very small by using many vanes; but, in that case, we increase the friction of the water flowing between them. We should seek the happy medium, which is different for each design.

Mr. Harris' paper on "The Theory of Centrifugal Pumps and Fans"* elicited discussion by Joseph Mayer, M. Am. Soc. C. E., Theodore Horton, Assoc. M. Am. Soc. C. E., the writer, and others. All these differed with Mr. Harris' theory. The present writer, in combating what he considered an erroneous method of attacking

* *Transactions*, Am. Soc. C. E., Vol. LI, p. 166.

Mr. Venable. the problem, failed to express at that time his appreciation of what was a valuable contribution to the literature dealing with centrifugal pumps.

Mr. Harris is chiefly interested in high lift pumps of the strictly centrifugal type, and the writer does not believe that the principles laid down in this paper are antagonistic to those advocated by Mr. Harris in his discussion of this paper, when the field in which Mr. Harris is working is borne in mind. As the best design for any required quantity and lift must be determined by considering the relative importance of losses of various kinds in the case in question, it is obvious that the proportions, where very high velocity of flow must be used in connection with small discharges, must be entirely different from those to be used where very large quantities move at small velocities. Therefore, the expedients that are advisable in high lift pumps with small volumes of flow are not the same expedients that must be used to secure equally good results where the relation of flow to head is reversed. The principles involved are, however, the same.

The writer thanks Professor Gregory for calling his attention to a mistake in his quotation from Professor Unwin. The expression as given by Professor Gregory, and the paragraph quoted, is correctly reproduced. The error arose in transcribing, and is to be corrected by substituting $(v_1 - v_2)^2$ where it is written, $v_1^2 - v_2^2$. The error is repeated on page 501. Otherwise Appendix I is correct as printed.

The expression, $(v_1 - v_2)^2$, represents the maximum amount of energy that could be dissipated, upon the assumption that the change in velocity of the water is as sudden as the change in section of the channel. This is a condition that can never be realized, and the expression, therefore, does not represent the actual loss in any case, but the amount of loss that exceeds a superior limit. The writer, therefore, objects to its introduction into formulas for the calculation of the behavior of a centrifugal pump. He believes that Professor Unwin recognizes its limitations, as he develops two sets of formulas, in one set of which this quantity does not enter. Of course, this formula is commonly used for calculating approximately the loss in head of water passing an abrupt change in section in circular pipes of moderate dimensions, where the factor of error is not very carefully considered. The writer still thinks that the head recovered in emergence of a jet of water from a small channel into a larger one has not been sufficiently studied, and that it is worthy of close attention. To distinguish this from entry head, and, at the same time, to call attention to the fact that it is somewhat like entry head, he has called this "emergence head" in the appendix. It is to be regretted that Professor Gregory did not

Mr. Venable.

give a full account of his experiments, which might have thrown some light upon the suggestion illustrated in Fig. 13. The experiments illustrated in Fig. 12 are sufficient to prove that the writer's contention is qualitatively correct, and that Appendix I was not written without considerable thought on the subject.

Mr. Higgins in his hypothesis that "an infinitesimal stream of liquid, bounded by a frictionless surface, moves in a mass of the liquid," evidently has in mind a streamlet in which the section normal to the motion is uniform, for which case his statement that "there is no change of pressure occasioned by this movement" is correct; but we are discussing cases in which the streamlet is under pressure and moving in a channel of varying section. Equation III gives the actual difference in pressure at a particle at rest before being acted on by the moving surface, and the same particle at a given point after being acted on by the moving surface, moving in a given direction; but it does not include the velocity head possessed by the particle with reference to its original position.

Mr. Smith's remarks are, like his published papers, highly interesting and instructive. The writer has long considered what Mr. Smith has said, in other papers, on radial vanes, and is inclined to agree with his analysis, but he cannot demonstrate it mathematically from the laws of motion. Mr. Smith attacks the heart of the problem when he takes up the study of the movement of the particle, considering its inertia. It is very difficult to tell by analytical study exactly how any particle at a distance from the surface of the runner is acted on by the runner, and the writer doubts whether the problem can be solved mathematically for even the simplest cases, such as that of radial vanes in a casing of uniform width, or of uniform section. However, in all pumping problems with which he has had to deal, the angle, β, has been very important on account of the large volume of water to be handled, and the difference between r_1 and r_2 has not been great enough to use vanes even approaching to the radial shape, as might be readily done in pumps of much less capacity and much higher lift, without entailing undue cost.

Before closing this discussion, the writer wishes to refer to his discussion on Captain Maltby's paper on "Hydraulic Dredging on the Mississippi River" presented to this Congress,* in which the effect of changing the number of vanes on the runner of a dredging pump, and the effect of pulsations upon the readings of piezometer tubes, and other matters, are considered with reference to particular tests. Captain Maltby's paper is referred to because the discussion is very closely connected with the subject of this paper. However, a correction to the writer's remarks there offered is necessary, as

* *Transactions*, Am. Soc. C. E., Vol. LIV, Part C, p. 496.

Mr. Venable. they contain one statement that is not in accordance with recent experiments, although that statement does not vitiate the conclusions arrived at in the discussion except to a very small degree.

In a paper presented before the American Society of Mechanical Engineers, but not yet published, Professor Gregory shows that the pressure throughout the section of a straight pipe in which water is flowing is practically uniform throughout a section taken normal to the direction of flow, irrespective of the velocity at each point. He does this by experiments with Pitot tubes. In the writer's discussion of Captain Maltby's paper, he has assumed that the total head of the velocity and the pressure is constant in the section referred to. While it does not seem likely that Professor Gregory's experiments justify the assumption that the surface of uniform pressure is absolutely a true plane, in the lack of a rigid proof of this, based on the laws of motion, but rather that there must be some slight bulging on account of the inertia of the water, especially if his hypothesis of the distribution of energy is correct, as contained in that paper, his assumption is doubtless much nearer the truth than the writer's in the case cited.

Bernoulli's theorem still applies, but the equipotential surfaces, so far as useful energy is concerned, take the form of elongated surfaces of revolution.

How valuable would be a comprehensive study of the distribution of pressure and velocity in enlarging and contracting pipes, and in jets issuing into a body of water, under a wide range of conditions!

Mr. Reynolds. IRVING H. REYNOLDS, ESQ., New York City. (By letter.)—As in the discussion of the writer's paper, several of the speakers have mentioned the same features, he will treat them together under the various heads, rather than in reply to individuals.

Speed and Pump Valves.—Mr. Mueller calls attention to the vital difference between piston speed and revolutions, and the writer quite agrees with him that piston speed is not of itself of so much importance as the number of revolutions, for the durability of the pump is, as the writer has stated, "practically proportional to the number of reversals per minute," and further, the quiet operation of the pump is dependent on the absolute seating of the valves before the plunger begins its return stroke, and into this element, the time enters very largely, and time also affects the inertia shock of the water in the pump passages.

The writer cannot agree with Mr. de Laval when he states that "there will be no more wear and tear on a high-speed pump than on a slow-speed pump, if the velocity is properly proportioned," for it is not velocity but shock that produces the greatest wear, especially on the pump valves.

No general rule can be given for speed, as constructive conditions limit the permissible stroke of the engine, and operating conditions the revolutions. In a general way, piston speeds of from 200 to 225, or even 250 ft. per minute, may be considered good practice for long-stroke, low-revolution engines, while piston speeds up to 300 ft. per minute are often desirable for engines which must have a very wide range of capacity, this high speed at the maximum capacity giving a very reasonable speed at the normal capacity, but, in determining the amount of valve area, all the conditions as to speed, revolutions, head, etc., should be taken into account. Mr. Reynolds.

In order that a pump may operate quietly and properly, it is essential that it shall fill absolutely, and the valves seat promptly, the proper filling depending on the valve area provided, which should be nearly constant for a given quantity of water, and not directly proportional to the speed of the plunger, while, in the prompt closing of the valves, the number of strokes per minute, as well as the type of valve used, are important elements; for instance, for a low number of revolutions, valves of large diameter and high lift may be used, but as the number of revolutions increases and the time for seating correspondingly decreases, the valves must be given less lift, either by making them of smaller diameter or of the multi-ported type, or they must be mechanically closed, and it is this fact that has brought about the almost universal use of small rubber disc valves in America, and although the writer knew they were also used in Europe, he had understood that multi-ported metallic valves, either automatically or positively controlled, were in more common use there than in America, or than were the small disc valves mentioned by Mr. Mueller. It may be stated as a fact that the small automatic valve fulfills all the requirements of pumping-engine service, as well as, or better than, the positively controlled valve and at much less cost.

Mr. Mueller expresses surprise that the City of Chicago has recently installed pumping engines with mechanically controlled valves, but this is explained by the fact that the City Engineer's specifications, under which bids for this machinery were invited, were "open," inasmuch as no particular type of engine was specified, and no limit was placed on the speed. Therefore, under the rather general American practice of awarding municipal contracts on the basis of the lowest bid, rather than on merit, it was hardly to be expected that slow-speed crank and fly-wheel engines could successfully compete against either high-speed or direct-acting machines.

Only three American cities have engines with mechanically controlled valves, and as these cities have ordered their later engines of the automatic valve type, it would not seem that the controlled type had sufficient merit to warrant its extended use.

Mr. Reynolds. The use of metallic valves in America has not been successful, as a rule, largely owing to the fact that many of the waters carry more or less sand or sediment which rapidly cuts the seats, but perhaps a metallic valve with a soft seat, as described by Mr. Hague, would meet American conditions very well, if the cost of the valve were not prohibitive.

As to the percentage of valve area, in proportion to the area of the plunger, the rule laid down by Mr. Hague is a conservative one, which can be safely used with the speeds and strokes of engines which he specifies, although the amount of valve area given is rather less than present practice demands.

It seems to the writer that it is better to state the valve area, not as a certain percentage of the plunger area, but as a given number of square inches for each million gallons pumped. For instance, 1 sq. ft. of valve area for each million gallons (U. S.) capacity gives a slightly greater percentage of area than Mr. Hague's rule, and a velocity through the valves of a little over 3 ft. per second.

All these rules assume valves of low lift and a moderate number of revolutions of the engine, but where the valves are of comparatively high lift, and more particularly where the engine operates at a high number of revolutions, it is necessary to provide greater area in order to reduce the lift and insure prompt valve seating.

Duty and Maintenance.—Mr. Chester, in his remarks, takes the pump designer to task as having in view only the matter of duty, the implication being that the practical features of reliability, simplicity and durability suffer thereby, this position being that assumed by many water-works managers a few years ago, when they were slow to believe that high economy could be obtained with reliable engines of moderate first cost.

While the writer thinks that engineers have reason to be proud of the greatly increased economy of pumping engines developed during the past twenty years, yet it is the operating engineer who has spurred them on, by always demanding higher economy and by often deciding the choice of a pumping engine largely on the duty guaranty, and water-works engineers, who ten years ago required a minimum of 135 000 000 ft-lb. duty, are now specifying from 160 000 000 to 170 000 000, and builders are occasionally guaranteeing even higher duty than the last-named figure. It is not a fact, however, that high duty is incompatible with reliability and low cost of maintenance, but, on the contrary, the writer believes that he is safe in saying that no type of pumping engine has ever been maintained at so low a percentage of its first cost as the modern vertical triple-expansion engine, and while there may have been a few instances of unusual depreciation, yet the writer's statement

remains good for this entire class of machines, no matter by whom built. Mr. Reynolds.

He recalls two vertical compound pumping engines, installed a little over twenty years ago, the builder guaranteeing to reimburse the purchaser for a period of twenty years for all repairs amounting to over 2% per annum on the first cost of the engines. These engines have now completed their twenty years of service, and the total repairs for the entire period did not exceed 2% of the contract price of the engines, or about one-tenth of 1% per annum. A triple-expansion engine was put in the same plant a few years after the first engines were built, on which the repairs were guaranteed not to exceed three-quarters of 1% per annum, and this engine has now run over ten years, without nearly approaching the amount allowed for maintenance.

A 20 000 000-gal. engine in Milwaukee, referred to in the writer's paper, and given as No. 1 in Table 1, has been in continuous operation for a period of 13½ years, being operated an average of 23½ hours per day for the entire period, at nearly 10% above its rated capacity, and during that time has had practically no repairs, such as have been necessary being made by the engineers at the station. This engine has never had a cylinder head, nor any of the steam valves removed, and more than one-half of the original 1 200 rubber pump valves are still in use and in good condition. Many other vertical triple engines can show practically as good a record for repairs, although the writer knows of none that have been in such absolutely continuous service.

The question of falling off in duty at slow speeds is often brought up by water-works managers, and it is a vital one as affecting their costs of operation. As the writer has stated before, this is a mater for which the engine builder is not primarily responsible, although the owner of the engine often is. Many times engines are purchased of far too large a capacity for the needs of the town, and, again, the requirements given for the duty test are for much higher water and steam pressures than those maintained in regular service. A few pounds steam pressure more or less has comparatively little effect on the economy, but a water pressure materially lower than that for which the engine is designed causes great loss in economy. The efficiency of the boilers, as well as the skill and attention of the engineers and firemen, are also very important factors in the economy of a plant.

All engines give somewhat lower economy when operated below their normal speeds, but this loss in economy does not usually exceed 10% down to one-half the normal speed, and is not peculiar to the high-duty engine, but is equally true of the direct-acting low-duty pump. A high-duty pump always gives relatively high duty

Mr. Reynolds. under all conditions, except when operated at such extremely slow speeds that the cut-offs cannot be used, and even under this abnormal condition its duty is better than that of the direct-acting pump, at equal speed.

The loss in economy is much more apparent in a small plant, where only one engine is used on the service, and where, if the service is direct, it is compelled to operate through an exceedingly wide range of speeds, and it is to this class of plant that Mr. Chester evidently refers, and the comparison he gives, between two engines in a "Missouri mining center," is not fair, because the low-duty engine is being operated at a constant speed and at practically its rated capacity, which is obviously the most favorable condition, while the crank and fly-wheel engine is being operated at varying speeds, down to one-fifth of its nominal capacity—an unfavorable condition.

As to the effect of independent auxiliaries on the duty, the writer must take issue with Mr. de Laval, for while it is true that a large portion of the heat in the exhaust of the auxiliaries can be recovered, yet it is a fact that the portion of work actually performed by the auxiliaries is done under wasteful conditions, and the writer does not believe that many water-works engineers, or Mr. de Laval himself, would install independent auxiliaries in a plant where it was absolutely essential to obtain the highest possible economy, either on a steam or coal basis. Independent auxiliaries are largely the outgrowth of the increasing speed of engines, both marine and stationary, but the speed of the pumping engine still being so moderate, the same reasons do not exist for having the auxiliaries detached.

Contrary to Mr. de Laval's opinions, the writer believes that the air-pump displacement should bear a definite relation to that of the cylinders, and that there is no occasion for varying this on any given engine. One auxiliary, however, may be independent, that one being the circulating pump for surface condensers, especially if there is a wide range of temperature between the water in summer and winter, but, on pumping engines, the condenser being located usually in the suction or discharge pipes, circulating pumps are rarely required.

Speaking of the surface condenser, Mr. Chester apparently takes exception to the writer's preference for the use of jet condensers, as against surface condensers, but in reality he takes the same position, for the writer stated distinctly that surface condensers are to be used "where there is a scarcity of water, or where the water contains such impurities as to render it unfit for use in the boilers."

Mr. Olsson calls attention to the peculiarity in the figures for steam consumption as shown in the test (Table 1, No. 7) of the

Nordberg quadruple-expansion engine, and by way of explanation, the writer quotes from the paper of the late R. H. Thurston, M. Am. Soc. C. E., entitled "The Steam Engine at the End of the Nineteenth Century,"* from which the following extract is made: Mr. Reynolds.

"*The Duty* reported was:
"Per 1,000,000 British thermal units......162,948,824 foot-pounds.
"Per 1,000 pounds dry steam.............150,254,138 "

"The power developed was 712 indicated horse-power; the capacity, 6,225,052 gallons per 24 hours, against a head of 602.7 feet. The weight of dry steam per indicated horse-power per hour was 12.26 pounds, which comparatively high figure is accounted for by the transfer of steam from the reheaters to the feed system, and by the small amount of heat absorbed per pound, where the feed-water is heated, as here, to 311 degrees Fahr. Heaters thus relatively increase water rates.

"The heat expended amounted to 185.96 British thermal units per indicated horse-power per minute, 11,158 per hour, which figures and those for duty on the heat units, the true basis, are about 10 per cent. better than the previous best record. * * *

"*A Trial made Without Heaters* shows well the influence of steam pressure without special gain by feed-water heating. It gave a duty—
"Per 1,000,000 British thermal units......147,525,000 foot-pounds.
"Per 1,000 pounds dry steam.............159,824,700 "
"and the weight of the dry steam per indicated horse-power per hour was 11.4 pounds, showing clearly that the system of heating the feed-water is to be credited with the exceptional economy of the machine. * * *."

Mr. Chester asks why the duty tests of the Worthington high-duty engines in Chicago were not placed in Table 1, and the writer would say that his reason for not doing so was because the figures, as given in the published account from which his abstract was made, are so inconsistent as to render them unworthy of serious consideration. This can be shown by an attempt to check the figures of "steam per indicated horse power," "duty per 1 000 lb. of steam," "coal per indicated horse power," etc., against each other, when it will be found that of the six tests given, only the fifth (E-1 204) can be checked even approximately. For instance, there is no apparent reason why the third test (E-1 200) should show a duty of only 161 676 942 ft-lb., with a steam consumption of 10 lb. per i. h. p. per hour, and a mechanical efficiency practically the same as E-1 204, which with the same steam consumption shows a duty of 174 735 801.

Mr. Olsson questions why the direct-acting engine should not give at least the same results as the fly-wheel engine, but it seems to the writer reasonable that it should not be expected to give as high economy, because the compensating device is, at best, only an

* *Transactions*, Am. Soc. M. E., Vol. XXI, p. 181.

Mr. Reynolds. approximate substitute for a fly-wheel, the stroke of the piston is not positively controlled, and, therefore, the clearances are greater and, contrary to expectation, the mechanical efficiency is not higher than that of the more complex fly-wheel machine.

In a well-known plant there are vertical compound engines of the high-duty direct-acting type, running under the same conditions as vertical compound engines of the crank and fly-wheel type, both sets of machinery having been installed at practically the same time, and yet, in regular operation, the engineers of the station state that more steam is required to operate the direct-acting engines at 20 000 000-gal. capacity than to operate the crank and fly-wheel engines at 30 000 000-gal. capacity. The writer thinks that this difference would hold good in nearly all large plants.

As to the method of conducting duty trials, it is perhaps simpler to base the duty on the steam consumption, but as Mr. de Laval says, we must consider the machines as heat engines, and, for the purpose of comparing various tests made where conditions of steam pressure and temperature vary widely, it is absolutely essential that a test should be computed on the B. t. u. basis. This is made apparent by Mr. Hague's statement that he hopes to obtain 200 000 000 duty on the engine now being installed at Reading, Pa., where superheated steam will be used.

This engine does not differ materially from other engines by the same maker, which have reached duties a little under 180 000 000, and it is fair to assume that the saturated steam and heat consumption of the Reading engine will not be appreciably better than that of previous similar engines, and the crediting of this engine with a higher duty, due to the superheat, would be a misleading comparison, for while it might indicate a higher efficiency for the entire plant, it need not necessarily indicate any higher efficiency for the engine itself. It is for such reasons as these that the Committee of the American Society of Mechanical Engineers, very wisely, the writer thinks, recommended the B. t. u. basis.

Types of Engines.—The writer agrees with Mr. Chester, that for capacities of less than 3 000 000 gal., especially where the range of capacity is very wide, the direct-acting steam pump has a very large field, and as previously stated by him, where fuel is cheap, the direct-acting engine may be used to advantage in capacities up to 5 000 000 gal., and the writer also thinks that of direct-acting pumps the triple-expansion is the best type.

He does not believe with Mr. Hague that the Worthington "high-duty" engine deserves at this date to be classed as one of the important types, for it has not sufficient merit to rank with the best crank and fly-wheel machines, nor is its first cost low enough to offer sufficient reason for its retention in the field of water-works

engineering. The vertical triple-expansion crank and fly-wheel engine stands first in general excellence for all capacities above 5 000 000 gal. Mr. Reynolds.

The vertical compound engine, while capable of being made a very excellent machine, as evidenced by the Louisville, New Bedford and other engines, including the compound machines in the St. Louis and Pittsburg Water-Works, must be regarded as a very special machine, built to meet some peculiar local conditions, and its use, for large units, is not likely to extend.

Coming to the horizontal engines, the cross-compound crank and fly-wheel type seems to meet all the requirements, and is well suited for all capacities up to 5 000 000 gal., and, where the head is moderately low, to even greater capacities.

Of the horizontal triple-expansion crank and fly-wheel engine, there are only a few examples, and the use of this class is not likely to increase.

The horizontal Gaskill engine, referred to by some of the speakers, has its chief merit in its compactness, and in this also lies its chief defect. It has served in the past a very useful part, but has no special advantages which are likely to result in its permanent use.

Of the direct-acting pumps, where economy is at all a factor, the horizontal triple-expansion low-duty type is to be preferred, but the writer cannot class pumps with so-called high-duty attachments as being among those likely to endure permanently, for when all has been said of them, they are mistaken, if ingenious, attempts to find means for storing energy which could be accomplished much better with a fly-wheel.

In brief, the writer thinks that under most conditions, all engines of 3 000 000-gal. capacity, and upward, should be of the crank and fly-wheel type, and that all large engines should be vertical.

All vertical crank and fly-wheel engines should be of the triple-expansion type, and all horizontal engines should be of the cross-compound type.

Direct-acting pumps are, as a rule, only suitable for moderate capacities, and should be of the horizontal type, the larger machines being of the duplex triple-expansion type, and the smaller ones of the duplex compound type.

Mr. Chester's suggestion to change the names of the various types can hardly be taken seriously, for the present nomenclature is logical, being based on the number of cylinders or "stages" in which the expansion is carried out, and the words, "compound," "triple," "quadruple," etc., give definite information as to the type, while, if these words referred to the number of "expansions," no idea of the form of the engines would be conveyed.

Mr. Reynolds. As to pumps driven by a belt from a Corliss or other high economy engine, as described by Mr. Dunham, this arrangement undoubtedly offers for small plants higher economy than can be had with direct-acting pumps of the ordinary type, and the writer has installed many engines of this general class, although usually driving the pumps by gearing, rather than by belts.

As to the turbo-centrifugal pump, while it is undoubtedly well adapted for certain special classes of work, it has yet to demonstrate its adaptability for general water-works service.

Professor J. E. Denton says on this subject:*

"While the mill and electric practice has developed the compound engine, pumping engines in the United States have been developed in the triple-expansion fly-wheel type to a degree of economy superior to that afforded by any compound mill or electric engine, and, for saturated steam, superior to that of the pumping engines of any other country. This is because their slow speed permits of greater benefit from jackets and reheaters and of less losses from wiredrawing and back pressure. These causes, together with the greater subdivision of the range of cylinder temperatures, have resulted in records made between 1894 and 1900 of 11.22, 11.26 and 11.05 pounds of saturated steam per indicated horse-power, with 175 pounds steam pressure, and from 25 to 33 expansions, in the cases of the Leavitt, Snow and Allis pumping engines, respectively, the corresponding heat consumptions being by different dispositions of the jacket drainage, 204, 208 and 212 thermal units per indicated horse-power-minute; while later the Allis pump, with 185 pounds steam pressure, has lowered the record to 10.33 pounds of saturated steam per indicated horse-power, with 196 heat units of consumption per horse-power-minute.

"The turbine can compete with these pumping engines only through the medium of a multiple-stage centrifugal pump, whose efficiency, taken even at 80 per cent., will probably impose too great a loss of motive power on the turbine system for successful competition with this high class of piston pump, since the friction loss of the latter is only 5 per cent. of the indicated horse-power."

In preparing his paper originally, the writer had in mind only the presentation, in a general way, of the engineering features of American municipal pumping-engine practice, but, due to the questions raised in the discussion, he has gone into operation matters to a greater extent than at first intended.

If any of the opinions expressed are thought to be erroneous, it can only be said in justification that, at least, they are based on an extended practical experience in the design, manufacture and operation of the class of machinery under consideration.

* "The Best Economy of the Piston Steam Engine at the Advent of the Steam Turbine," a paper presented before the Mechanical Section of the International Congress of Arts and Sciences at St. Louis, September 23d, 1904.